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Technical Report 405

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EVALUATION OF THE UTILITY OF THE THEORY OF SIGNAL DETECTION FOR TARGET ACQUISITION STUDIES

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EDUCATIONAL TECHNOLOGY AND SIMULATION TECHNICAL AREA

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This study explored the effects of instruction and target-to-background contrast, within the framework of signal detection theory, on the performance of Army aviators during a target acquisition task. Its goal was to determine whether the typical measures of target acquisition performance (reaction time and frequency of hits) would be influenced by the type of experimental instructions given to the test participants, and whether the signal detection parameters of bias and sensitivity would reflect instructional and target-to-background contrast differences, respectively. In addition, a (Continued)

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critical goal was to determine whether the signal detection measures could be used, by means of an analysis of covariance, to remove the bias effects of instructional differences from the reaction time and frequency of hit data.

A target acquisition task during a simulated helicopter pop-up maneuver at one thousand feet altitude was presented, with a 30-second exposure time. The observer's task was to search for a single 20-foot military tank in various field locations, and at a slant range of 2500 feet. The scenes were presented with and without targets, in order to obtain an observer's hit rate and false alarm rate, the basic procedural requirement for signal detection theory. Three levels of instruction and two levels of target-to-background contrast were employed. Twelve Army helicopter pilots were assigned to each instructional level, with target-to-background contrast as a within factor. The design was presented in the form of a 4 x 4 Latin Square to assure experimental control of the effects of trial sequence, target background, and the order of presentation of target-to-background contrast.

The experimental differences in instruction and target-to-background contrast had a statistically significant effect on the reaction time and frequency of hit data, and were reasonably represented by the signal detection measures. The latter can be successfully used to adjust the frequency of hits between target acquisition studies, to remove the effects of different instructional sets as well as different target-to-background contrast levels. The signal detection parameter for sensitivity represents the primary covariate for the adjustment of hits due to its primary statistical dependence on the frequency of hits, with the parameter for bias playing a lesser role. The signal detection parameters, however, do not adjust for the differences in reaction time. This is due to the dependence of the signal detection model on frequency of hits and false alarms, and the lack of correlation of these measures with reaction time. Within certain procedural constraints, the signal detection model possesses utility for applied target acquisition studies.

Technical Report 405

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Aircrew Training in
Target Acquisition

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FOREWORD

Target acquisition represents one of the most challenging and critical functions performed by military aviators. Many research activities and programs have been conducted to determine the limits and capabilities of human performance. The present effort grew out of Project SEEKVAL, which was a Joint Services Program, conducted for the Deputy Director, Test and Evaluation (DDT&E), Office of the Director, Defense Research and Engineering. The Army Research Institute for the Behavioral and Social Sciences (ARI) provided technical advisory service to the program.

One of the important procedural problems identified during the above effort was the necessity to control for operator response bias which tended to confound the results of different SEEKVAL experiments. The present study was designed to investigate the utility of signal detection theory with respect to this problem. Work was done in the Human Factors in Tactical Operations Technical Area of ARI, under Program Element 6.27.22A, Project A765, Task C (FY 78). Outside the Technical Area, Dr. E. Johnson provided his critical reviews and comments, and Dr. R. Johnson his invaluable help in the set-up, calibration and control of the laboratory equipment, plus running of the test participants. Ms. B. Popelka prepared the complex stimulus materials and laboratory test procedures, and ran test participants; Dr. J. Mellinger advised on statistical analyses procedures; and Ms. F. Grafton assisted in data processing.

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EVALUATION OF THE UTILITY OF THE THEORY OF SIGNAL DETECTION FOR TARGET ACQUISITION STUDIES

BRIEF

Requirement:

Target acquisition is a difficult and complex human task where the role of an observer's response bias as a result of experimental instructions is not fully understood or appreciated. This variable has been left uncontrolled in what otherwise can be considered sophisticated laboratory and field experiments. The results of such experiments are frequently inconsistent with one another, which in part may be due to the use and effect of different instructions that are given to the test participants.

The theory of signal detectability appears suited for the investigation of this problem area. It postulates that an observer has a continuum of response states rather than a discrete sensory threshold to a stimulus. In doing so, it makes an explicit distinction between two characteristics of an observer's response, i.e., (1) his sensitivity to the stimulus (d'), and (2) his prevailing response bias (Beta).

Time to detection and the number of hits are the usual dependent measures of a target acquisition experiment. They can also be considered to be operationally relevant measures, which are compared between different experiments. The d' and Beta values of a signal detection experiment, as dependent measures, are usually evaluated in and of themselves without comparison to other dependent variables. Moreover, it is difficult to evaluate the implications of these measures relative to the operationally relevant dependent measures that may be associated with them. The direct evaluation of these latter measures, when free of response bias, would have more utility than information on d' and Beta alone or when used in conjunction with them. In effect, a capability is needed to transform operationally relevant measures to a bias-free level. The applicability of the signal detection model for the applied problem areas of target acquisition, and the utility of its parameters to accomplish the objective warrants investigation. Consequently the following hypotheses and goals were addressed.

1. Target acquisition performance (reaction time and number of hits) will differ as a function of the type of instruction and level of target-to-background contrast given to the test participants.

2. The signal detection parameters of Beta and d' will reflect the effects of the different instructional levels and target-to-background contrast, respectively.

3. To evaluate the utility of the signal detection parameters of Beta and d', when used in an analysis of covariance to adjust the operationally relevant dependent measures to a bias free level of performance.

Procedure:

A two factor experiment involving three levels of instruction and two levels of target to background contrast was employed. Twelve Army helicopter pilots were assigned to each instructional level, with target to background contrast as a within factor. The design was presented in the form of a 4 x 4 Latin Square to assure experimental control of the effects of trial sequence, target background, and the order of presentation of target to background contrast. The above design was repeated in a second experiment which changed only the levels of target to background contrast, and which used different test participants. In the first experiment, contrast levels typical of field studies (35 and 45 percent) were used; while in the second experiment, contrast levels typical of laboratory tests (14 and 17 percent) were used.

A target acquisition task during a simulated helicopter pop-up maneuver at one thousand feet altitude was presented, with a thirty-second exposure time. The observer's task was to search for a single 20 foot military tank in various field locations, and at a slant range of 2500 feet. An infra-red scene of European terrain was simulated, which was presented on a 50 x 50 degree backlighted screen viewed at 20 inches. The scenes were presented with and without targets, in order to obtain an observer's hit rate and false alarm rate, the basic procedural requirement of signal detection theory.

Findings:

1. Instructional set is an important determinant of aviator performance during target acquisition with respect to reaction time and the number of hits, which confounds the results of similar experiments when this variable is left uncontrolled.

2. The signal detection model provides a reasonable representation of the sensitivity and bias effects associated with instructional set and target contrast, with some loss of precision due to its application under simulated "field" conditions.

3. The signal detection parameters associated with sensitivity and bias can be used in an analysis of covariance to adjust the frequency of hits between target acquisition studies, to remove the effects of different instructional sets as well as different contrast levels. However, these parameters would also remove the difference in the number of hits due to different sensor systems.

Utilization of Findings:

1. Target acquisition studies conducted for the military should rely on a single set of standardized instructions to help assure the control of observer response bias. In this respect, emphasis on the

accuracy of response is recommended as it leads to more "hits" with fewer "false alarms," without an excessive increase in response time.

2. The special problems have been identified and procedures defined for the effective application of the signal detection model to the applied problem area of target acquisition.

3. The signal detection parameters of the test participants can be averaged and used as dependent variables to compare the effectiveness of different sensor systems, without the confounding effects of response bias.

4. When identical systems are tested, at different times, the signal detection parameters can be used in an analysis of covariance to remove the effects of non-system-related factors of sensitivity and bias from the operationally relevant dependent measures.

EVALUATION OF THE UTILITY OF THE THEORY OF SIGNAL DETECTION FOR TARGET ACQUISITION STUDIES

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EVALUATION OF THE UTILITY OF THE THEORY OF SIGNAL DETECTION FOR TARGET ACQUISITION STUDIES

CHAPTER I. INTRODUCTION

Problem

The acquisition of targets from military aircraft represents a critical problem for the military. Despite significant improvements in sensor, guidance, and ordnance systems, their effectiveness is nullified by the inability of the pilot (or co-pilot) to detect and identify targets. Extensive research has been conducted in an attempt to isolate the critical variables, and their parameter levels, that affect human performance. Such information is needed to assist the development of techniques, aids, and procedures for the enhancement of pilot performance, and for prediction purposes. The results of laboratory studies and field studies, however, have shown wide variability as well as contradictory (or inconsistent) results, with respect to the key target acquisition variables, which has prevented the comparison of related experimental data.

In general, the critical independent variables are considered to be:

- contrast of target to background
- type of target background (e.g., amount of trees, masking foliage and competing objects)
- target image size (i.e., visual angle)
- moving or stationary target
- aircraft velocity (or exposure time)
- search area (or field of view).

The dependent variables are usually reaction time and the number of successful acquisitions.

Of the above independent variables, target acquisition is particularly sensitive to target contrast, with significant performance changes occurring for incremental changes in contrast as small as 5% (Ozkaptan, 1968). The inconsistency of results between experiments has usually been attributed to the difficulty of controlling target contrast. Poor contrast control has affected both the reliability of results, and the comparability of different experiments.

Another problem area that has generally been overlooked, however, is the observers' mental set or response bias as a result of risk taking behavior, previous results, or explicit instructions. The sensitivity of target acquisition performance to this factor is not fully appreciated or taken into account, with major experimental emphasis being devoted to the control of physical variables such as contrast. Instructions given to observers in various experiments, in this regard, have been treated casually and have been highly varied in nature. Instructions have been given which emphasize caution (e.g., respond only if you would be willing to change course and prepare ordnance). Other instructions have stressed speed of response (e.g., identify as many targets as you can). In some studies, the type of instructions given to the observers is not even reported.

This problem manifested itself in a recently concluded Joint Services Target Acquisition Program (SEEKVAL, 1976). This program consisted of a series of field and laboratory experiments designed to evaluate and validate different simulation techniques (movie films and three dimensional terrain tables). Designs were developed to assure comparability of the data between the different experiments. Instructions, however, were not controlled. It was found that the results between the different experiments could not be compared. The variability of instructions was probably one of the contributing factors to this problem.

A large body of experimental literature has indicated the importance of instructions in determining the nature of a subject's response (Baker, 1963). The studies have shown that instructions must be controlled, if the influence of subject response bias on performance is to be avoided. It can be assumed that lack of adequate attention to this factor in target acquisition studies has confounded the obtained sensitivity thresholds with uncontrolled response biases. It is important to understand the specific effect of instructions on operator performance, i.e., the degree performance is a function of response bias and/or sensitivity. In addition, this factor along with target contrast and other considerations must be controlled, treated as an independent variable, or taken into account by means of appropriate statistical procedures to assure performance data that can be effectively interpreted and compared between different though related experiments.

Signal Detection Theory

The theory of signal detection (TSD) appears suited for the investigation of the above problem area. Unlike classical psychophysical assumptions, which underlie current target acquisition studies, TSD postulates that an observer can have a continuum of response states rather than a discrete sensory threshold to a stimulus. In doing so, it makes an explicit distinction between two characteristics of an observer's response, i.e., (a) his sensitivity to the stimulus (d'), and (b) his prevailing response bias (B). As such, it questions the validity of classical sensory thresholds, and views them as misleading, since they

do not account for the latter. As noted earlier, an observer's response bias may be influenced by various "utility" variables such as instructions, cost to the observer, and a priori probabilities. TSD explicitly delineates the effects of these variables, which are either implicit or not considered in the conventional experiment. Like psychophysics, its application is limited to near threshold stimuli, or low signal to noise ratios. Its foundations are in decision and detection theory. The basic principles of the theory are described in Appendix A.

TSD enables comparison within and between experiments with different instructions and other predisposing factors for response bias, so long as the procedural requirements and assumptions of TDS (as described later) are met. According to Coombs (1970), "It is, of course, a very substantial accomplishment for a theory to provide predictability and integration over a wide variety of experimental conditions and procedures. It appears that for a given observer and a given S/N ratio, d' is reasonably constant over variations in Beta induced by changing the prior odds and payoff matrix and, for the most part, over variations in procedures . . ." (p. 199).

Despite the increasing familiarization of the scientific community with TSD and awareness of the limitations of the classical concept of a threshold, many experimenters in the area of vision still retain the use of the concept of threshold (Haber & Hershenson, 1973). This omission may be due to one of several reasons. TSD is much more difficult to apply, particularly in an applied problem area such as target acquisition.

For any given experimental condition (e.g., contrast level, slant range, etc.) two types of stimuli must be presented. This includes, for reasons described in Appendix A, a stimulus with target (signal), and a stimulus without a target (noise). In addition, each type of stimulus must be presented a sufficient number of times to obtain an adequate frequency of hit rates and false alarm rates. This obviously increases the treatment requirements for any given experimental condition by a significant amount. Five hundred trials per experimental condition is not considered unusual (Green & Swets, 1966). Some experimenters have used as few as 40 trials with success (Harvey & Michon, 1974). In classical TSD experiments, the number of trials is not too serious a constraint since the same stimulus can be used repeatedly. In target acquisition, however, each trial would require a new stimulus, since the subject would otherwise know where the target is located. This increases by many-fold the problem of stimulus preparation and the associated control problems (e.g., contrast and background). The problem is further compounded in field studies, where a limited number of background sites may be available.

It is also possible that the problem of response bias is not fully appreciated in the visual domain, particularly with respect to target acquisition where the researchers are generally engineering oriented. TSD is also essentially an individual model. Sensitivity and bias levels are determined for each subject. Target acquisition on the other

hand, depends primarily upon summary statistics for prediction purposes. As a result, the signal detection parameters of each subject must be averaged as described in Chapter V. Some additional problems of application are also described in the next chapter.

In addition to the above procedural problems, the measures of d' and Beta are essentially abstract. They are also generally evaluated in and of themselves as dependent measures relative to the independent variable of interest. While of importance and the very foundation of TSD, the d' and B scores do not directly indicate what the operationally relevant measure would be if it were free of bias. In addition, it is difficult to equate or compare the latter measures between experiments, even though the d' and Beta values may be known. This is due to the fact that both the TSD parameters and the reaction time measures (or other dependent measures of interest) must be consistent in the results of the two different experiments that you may wish to compare. For example, if each experiment has the same d' measure for a given experimental condition but a different reaction time measure, no comparison can be made. The same is true if each experiment had the same reaction time measure for the experimental condition, but a different d' value. Even if the TSD parameters and other dependent variables are consistent, comparison can only be made if the subjects' responses have the same standard deviation (as explained in Appendix C).

In target acquisition, time to detection and frequency of hits are the primary measures of interest. The direct comparison of these measures (when free of bias) will have more utility than information on d' and B values alone. In effect, a capability is needed to transform the operationally relevant dependent measure to that value it would have if it were free of bias. This would provide direct comparability of data between experiments.

It was reported by Green and Swets (1966) that: "Whether or not one could extract a useful measure of reaction time, one that is independent of the response criterion, from a curve analogous to an ROC curve is an open question" (p. 325). A review of the literature revealed only one such attempt. Harvey (1974) in a traditional signal detection study, adjusted the motion thresholds of operators on the basis of their HR-FAR and ROC values to the same psychophysical threshold (i.e., a detection probability of .73). In this important precedent, six motion thresholds bracketing an estimated threshold speed were used. The relationship between the d' values and the six motion thresholds of each subject were determined by regression analysis. The beta weights obtained from this analysis were used to determine the threshold speed for each subject that would have given d' = 1.25. This value corresponds to a detection probability of .73, which is the equivalent of a traditional psychophysical threshold.

In the present experiment, the goal will be to remove the source of variance associated with response bias for the subjects as a whole, rather than adjusting the data for each subject to a desired sensitivity level. A means will also be available to validate the utility of the

procedure, by using three different groups of test participants and instructional levels, whose data can be compared after the removal of response bias as a function of instruction.

Hypotheses and Experimental Goals

The primary goal of this study is to apply signal detection theory to evaluate its utility to represent the bias effects of different instructional sets, and to remove this source of variance through analysis of covariance. The specific experimental objectives are as follows:

(a) Target acquisition performance (reaction time and number of hits) will differ as a function of the type of instruction and level of target-to-background contrast given to the test participants.

(b) The signal detection parameters of Beta and d' will reflect the effects of the different instructional levels and target-to-background contrast, respectively.

(c) To evaluate the utility of the signal detection parameters of Beta and d', when used in an analysis of covariance to adjust the operationally relevant dependent measures to a bias-free level of performance.

The use of several instructional sets will serve two purposes. It will demonstrate the impact of instructions on target acquisition performance, as well as the signal detection parameters of d' and Beta. It will further indicate the utility of the signal detection parameters to adjust the data, as a function of different instructional sets, to an equivalent and bias-free level of performance. In effect, any significant differences between the data of the instructional groups should after adjustment be rendered as statistically insignificant.

CHAPTER II. RESEARCH DESIGN CONSIDERATIONS

Application of Signal Detection Theory

The application of signal detection theory to an applied problem area such as target acquisition involves several departures from its traditional use. They are as follows:

Threshold Values. In a traditional study which attempts to find a threshold value, a conventional psychophysical method of limits cannot be used, since a fixed signal to noise ratio must exist. As a result, a set of different values must be chosen which bracket the estimated threshold value. This, in effect, adds the complexity of another experimental factor to the experiment. This problem, however, is alleviated in a target acquisition study at a fixed slant range where only probability of performance or reaction time are the desired for a given

experimental condition. This permits each condition to have a fixed signal to noise ratio, rather than having to introduce multiple levels of each condition to find a threshold value. The problem, however, is more complex for closing slant ranges. In this case, the dynamic visual scene has a varying signal to noise ratio until the moment of detection. Although average time and probability of detection can be recorded, the dependent variable (DV) must be broken into discrete categories representing different slant ranges (signal to noise ratios) to permit proper analysis of the data under the TSD paradigm. Due to the additional complexity involved with this procedure, only the static helicopter pop-up maneuver was selected for experimental purposes.

False Alarms. In a traditional signal detection study, the stimulus is usually in a fixed location which permits the observer to always be right by simply saying yes. For this reason (as discussed in Appendix A), a noise or nonsignal condition is added to determine a subject's willingness to guess that a signal is present. In target acquisition studies, however, the target is placed in varying locations with competing objects in the scene. The subject, as a result, can have a false alarm response to the stimulus with a signal, unlike the traditional study. This poses a problem of how to treat these additional false alarm values. In the present study, they were treated as a regular false alarm and added to the number of false alarms obtained under the noise only condition. It is possible, however, that a noise only condition may not be necessary. This aspect, however, warrants a separate study.

Slope Values. The slope (b) of the receiver operating characteristic (ROC) curve must be known for the calculation of the signal detection parameters. One hit rate-false alarm rate (HR-FAR) pair provides only one point on a ROC curve, and by itself is not sufficient to determine the slope value. A slope value of one is usually assumed, but if incorrect can distort the d' value as described in Appendix C. Consideration was given to applying three different instructional sets to each observer, which would provide three HR-FAR pairs for the calculation of a slope value. However, certain problems mitigated against this approach. First, there is the problem of whether subjects could effectively change their instructional set between conditions, particularly when three levels of instruction are used. The number of instructions could be reduced to two. This, however, would (a) lead to loss of accuracy in estimating the slope of the ROC curve; (b) limit the scope of the evaluation of instructional effects on performance; and (c) affect the accuracy of the regression formulas in determining the relation between d' and Beta with reaction time and the number of hits. The confounding of instructional sets within the same subject could also be controlled by testing the subjects on different days. It was determined, however, that it is nearly impossible to assure the use of the same Army helicopter pilots on successive days. As a result, it was decided to use the instructional variable as a between factor. This introduced the problem of subject matching which is discussed in the next chapter.

The problem of obtaining three HR-FAR pairs with one instructional set for each subject was solved by the use of the following four confidence ratings which will yield three such pairs for each subject as described in Appendix C:

1. No target--positively not there
2. No target--probably not there
3. Target--probably there
4. Target--positively there

To each stimulus presentation, with or without target, the observer responds with one of the above confidence ratings which determine his hit rate or false alarm rate (Pastore, 1974).

Number and Ratio of Stimuli With and Without Signals. The ratio of stimuli with a target (signal) to stimuli without a target (noise) shall be kept at 50-50 in accordance with conventional practice. It allows HR and FAR to be equally accurately estimated. This ratio is also somewhat comparable to what can be expected in the real world when seeking a target.

The number of stimuli will be kept at 60 treatments per experimental condition (i.e., 30 with signal and 30 without signal). As reported in the preceding chapter, as few as 40 treatments and as many as 500 treatments have been used per condition. In the present experiment, the maximum number of stimuli for each experimental condition was determined by taking into account the number of independent variables, and the number of required practice and familiarization trials. A maximum of 4 hours of data collection was desired for each observer (including rest periods). It was felt that a longer period of time would introduce factors, such as boredom and reduced motivation, which could interfere with a subject's experimental set. As a result, the design and number of treatments were deliberately limited to the minimum conditions necessary to meet the experimental objectives.

Independent Variables. Signal detection theory depends upon the signal to noise ratio for the determination of response sensitivity (d') and utility variables (pay-off) for response bias (Beta). These variables in the present study were represented by target-to-background contrast and instruction, respectively.

Three instructional levels were used to help illustrate the range of possible bias effects for a given signal to noise ratio. The expected influence of instructional set or bias level on the subjects' decision criterion or likelihood ratio is illustrated in Figure 1. Theoretically, the proportion of hits and false alarms should change relative to each instructional set. The instructional levels will be selected to respectively increase or decrease an observer's caution, as illustrated in Figure 1. The specific instructions used are presented in Chapter III.

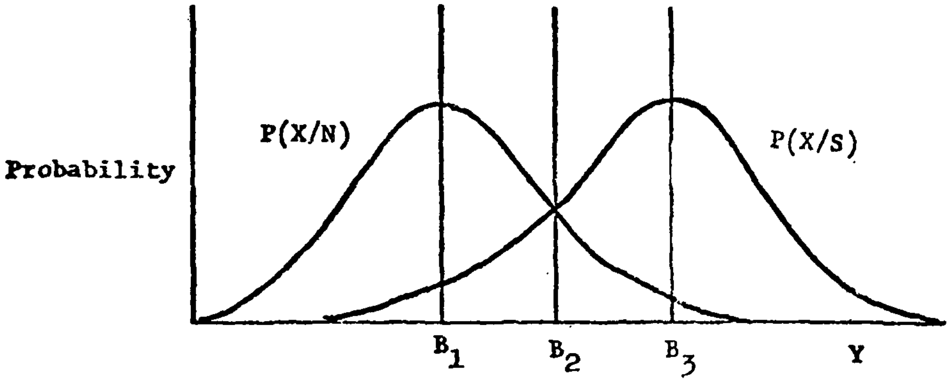

Figure 1. Potential distribution of bias effect (B) due to varying instructions.

Two contrast levels were used to illustrate the change in sensitivity (d') as the signal to noise ratio is changed. This is illustrated in Figure 2. As can be seen, the "noise" and "signal" distributions should, theoretically, move apart as the contrast level (or signal to noise ratio) is increased. A given bias level as illustrated by the vertical line B should remain stationary. It can be seen in Figure 2 that this will cause a change in the HR while the FAR stays constant. Another item of interest is the fact that, should interactions occur between instructions and contrast, the ability to construct a ROC curve and to meaningfully conduct an analysis of covariance would be lost. Such an event would severely limit the utility of TSD for this problem area.

Target Acquisition Variables

As mentioned in the first chapter, target acquisition performance is influenced by many variables. The variables selected and those held constant for the present experiment are as follows.

Black and White Versus Color Scenes. The problems and methodology of black and white (brightness) contrast is well understood. No way has yet been found, however, to effectively account for color contrast. While this has not prevented the use of color stimulus materials in many experiments, it adds a significant and complex dimension for the control of target-to-background contrast. The present experiment, as a result, will rely on black and white scenes.

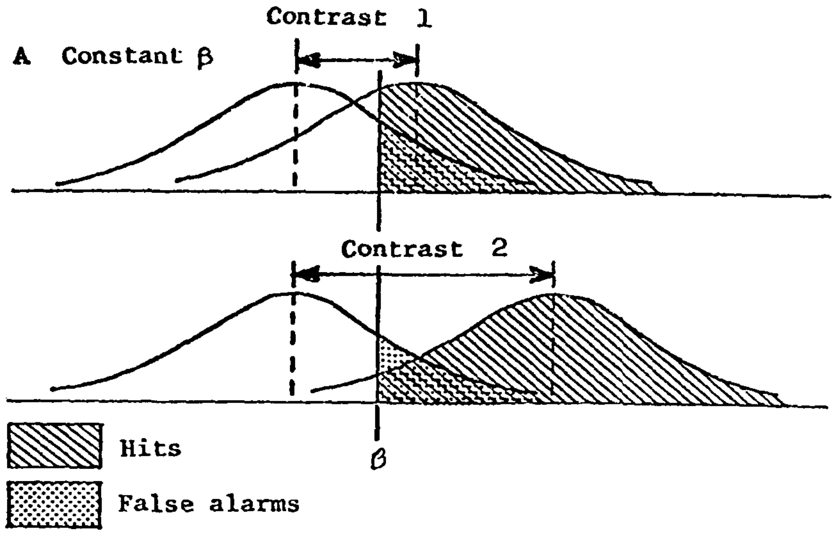

Figure 2. Illustration of the effect of changing signal to noise ratio.

Target Type and Orientation. Both type of target and its orientation affect detection thresholds. Unique shapes and discriminable features such as protruding gun barrels offer supporting cues against otherwise natural backgrounds. One Army tank will be used as the target. Its side profile view will be displayed, to maximize its discriminable features.

Slant Range and Target Visual Angle. The visual angle to be subtended by the target will be a function of the slant range. A pop-up altitude of 1000 feet and slant range of 2500 feet will be simulated. This corresponds to the median slant range used in the SEEKVAL study. At this slant range and a 20-inch viewing distance, a 20-foot tank will subtend a visual angle of 30 minutes of arc. Previous studies have indicated that even targets that are appreciably above visual threshold levels cannot be readily detected due to low contrast and basic search requirements. Such studies have shown that as much as 24 seconds may be required for the search process.

Target Background. Target background or amount of "clutter" is a difficult variable to quantify. Some studies have simply used general geographical categories, such as deserts, hilly plains, partially forested farm land, etc. More precise attempts to quantify this dimension have been unsuccessful (SEEKVAL, 1976). Target background for the present study will be limited to open and moderate terrain that is partially forested, without any geographical extremes such as mountains and deserts. The experimental apparatus for this study will permit the use of the same background with and without a target. Nevertheless, a

different background will be used with each stimulus condition to avoid any familiarization and learning effects.

Field of View (FOV). Field of view or area to be searched increases search time and can affect the target's visual angle (when presented on a fixed viewing surface). The normal binocular field of view (FOV) is approximately 120° in both the vertical and horizontal direction (Kaufman, 1966). An operator, however, can obviously scan up to 360° or limit his attention to a briefed area. Search time will vary with the area to be searched. Appreciable search time is involved in target acquisition, however, even if only an 8-inch CRT monitor is used. While a realistic 120° FOV would be desirable, the present requirements were a function of a trade-off subject to luminance, resolution, and cost requirements. As a result of these considerations, a 50° FOV appeared to be the optimum compromise. It was large enough to give the impression of realistic viewing while meeting the desired luminance and resolution requirements, and could be viewed comfortably with the observer's head on a chin rest. The simulated slant range was set at the center of the screen, with ±1000 feet on either side.

Exposure Time and Scene Veridicality. A 30-second exposure time was used. This corresponded to the time typically used under operational conditions, since detection by the enemy and counterfire usually requires at least 30 seconds. At the slant range to be simulated, the viewed scene will be comparable to that of the three-dimensional world. This is due to the fact that beyond 300 to 500 feet, binocular cues are lost, and only monocular cues dominate for depth perception. In addition, parallax cues are also lost at the longer slant ranges. Thus the use of two-dimensional stimulus materials will be comparable to real world viewing (Fowler, 1972).

Briefed or Unbriefed Targets. In an operational setting, targets can be briefed or unbriefed. While performance differences are significant, they vary consistently by only an order of magnitude (Ozkaptan, 1968). In the present experiment, targets will be unbriefed. This imposes an additional level of test difficulty that will help to differentiate between instructional sets.

Target to Background Contrast Target contrast is a difficult variable to control and consequently affects the contrast levels studied in laboratory and field studies. Target contrasts as low as 5% have been studied, when it has been possible to control contrast levels within ±2.5%. Laboratory studies, however, typically simulate contrast at approximately the 15% level, and field studies at the 50% level. The specific contrast levels used in this study are described in Chapter III.

Visual Display Considerations

Visual Resolution. A display resolution was desired that would permit target acquisition performance comparable to natural viewing conditions. Basic human visual resolution is generally accepted to be

1 arc min. In this respect, the visual resolution chart is referenced to a 1 min of arc visual capability (i.e., 20/20 vision). Visual resolution, however, varies considerably with contrast and luminance as shown in Figure 3, and with position on the retina in terms of distance from the fovea (Smith, 1966).

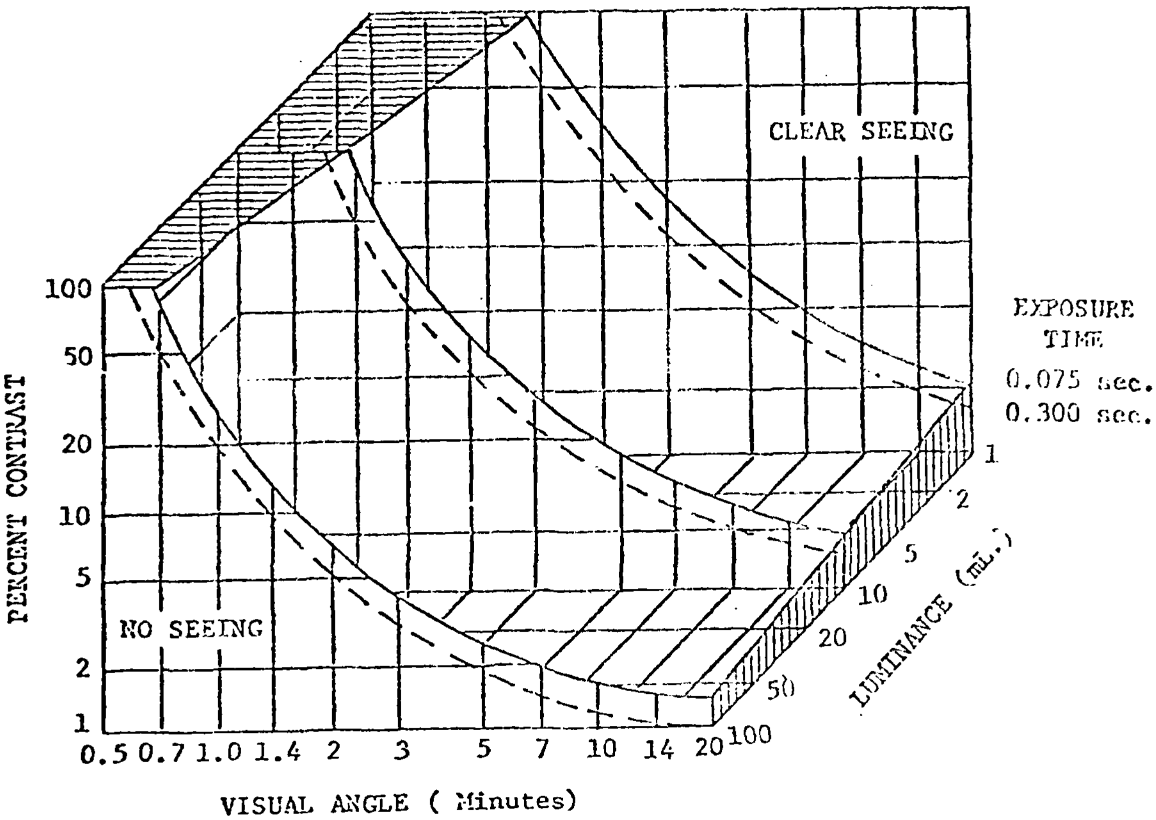

Figure 3. Background luminance and contrast required for bars subtending various visual angles under daylight conditions.

Under dynamic or normal viewing conditions, visual resolution or the visual angle at which targets can be detected, recognized, and identified is appreciably less. "A rough guideline for target acquisition capabilities of the human eye is as follows: target-detection--when target subtends an angle of 2 to 5 arc minutes; target recognition--at

an angle subtended of 4 to 10 arc minutes; and target identification--at an angle subtended of 8 to 16 arc minutes" (Bailey, 1974). These values are influenced by many variables, in addition to visual capabilities.

As a result of the above considerations, a visual resolution requirement of 3 arc minutes was established. This requirement has been met by the apparatus described in Chapter IV. The resolution of the displayed scene will be better than this value (i.e., eye limited) up to a simulated slant range of 8,000'. This range represents realistic operational conditions and is near the threshold of performance for field target acquisition (SEEKVAL, 1976).

Illumination. In most visual display systems, "apparent" brightness is generally sufficient for the intended objectives (e.g., training). A luminance of 1 to 5 foot lamberts, for example, is adequate to provide an "apparent" daylight scene. Vision is still in the photopic range. As described in Chapter IV, the projectors provided 114 foot lamberts on the screen. This value, however, was reduced to a range between 1 and 3 foot lamberts when the background slides were introduced. At this light level a subject's visual acuity is reduced. Figure 4 shows the relationship between visual acuity and light level. Near maximum visual acuity occurs at about 100 FL where the slope of the subsequent improvement begins to level off. "Even though we must grant that visual acuity continues to increase beyond this luminance level, it is apparent that the sensory response of the human eye and the related perceptual response of the human observer changes very little. In terms of perceptual fidelity, it may be concluded that visual fields with more than 100 millilamberts luminance are approximately perceptually equivalent, and that relative to visual acuity, a simulation display technique that is capable of generating 100 millilamberts possesses almost 100% perceptual fidelity" (Buddenhagen, 1961).

The practical implication of the above recommendation for simulation purposes was evaluated by Harris (1974) relative to the influence of illumination on probability of detection at varying viewing ranges. When probability of detection, relative to illumination and viewing range are taken into account, performance is comparable or identical at 100 and 50 FL, due primarily to the fact that with reduced illumination, performance is lost primarily at the more distant ranges and less at the more close-in ranges. The author states that "the acceptable tolerance in scene luminance depends upon the specific experiments to be performed and the precision desired to the experimental results. It would be expected, however, that differences in performance between 50 FL and 100 FL scene luminance will be lost in the noise of individual differences and other experimental factors." While light values in this range were desired, they could not be achieved with the equipment available.

Briefly recapitulated, the following target acquisition variables were held constant: FOV, target type and orientation, the target's visual angle, illumination, and the ratio of scenes with and without

targets. Target-to-background contrast and instruction set served as the independent variables.

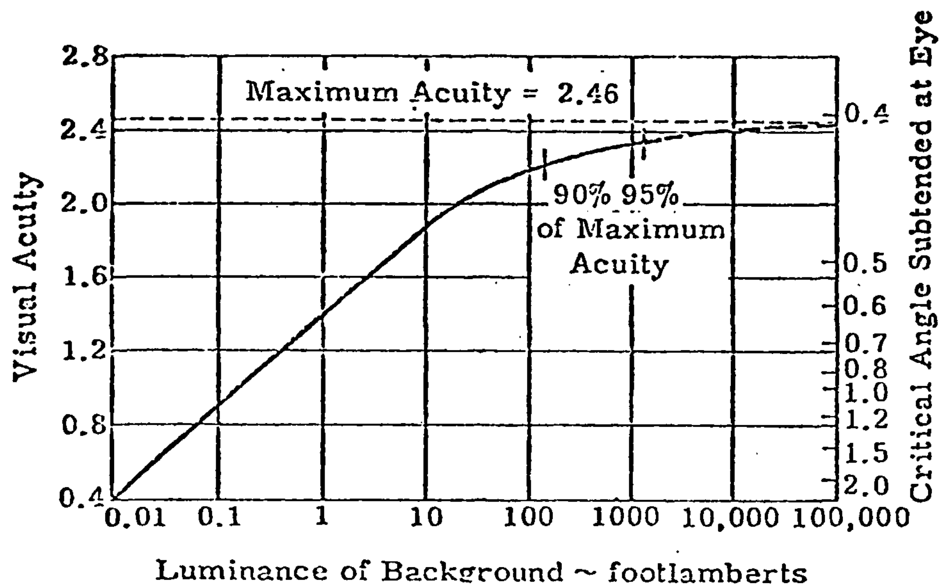

Figure 4. Variation in visual acuity with background luminance for a black object on a white background.

CHAPTER III. METHOD

Independent and Dependent Variables

Independent Variables. The independent variables of the experiment are three levels of instruction and two levels of contrast. Three levels of instruction were selected to represent a large range of bias effects (i.e., from a low to high level of caution). The selected instructions also represent the types that typically might be used. They include an emphasis on accuracy and speed, and a neutral level which is unstructured. The instructions have been stated in a military context, as shown below. In addition, an auditory tone was presented at 15 and 25 seconds to reinforce the intent of the instruction. The complete set of instructions is contained in Appendix B.

1. Accuracy Instructions.

Your task is to search the viewed scene and to decide whether a target is present or absent as accurately as you can. An accurate response is essential in order to reliably alert supporting forces, and

to minimize additional pop-up maneuvers. Use as much of the available 30 seconds exposure time as feasible to assure the accuracy of your decision as to whether the target is present or absent. An auditory signal will be presented after 15 and 25 seconds have elapsed to assure the accuracy of your response in the time remaining.

2. Neutral Instructions.

Your task is to search the viewed scene and to decide whether a target is present or absent. Each scene will be presented for a maximum of 30 seconds. An auditory signal will be presented after 15 and 25 seconds have elapsed.

3. Speed Instructions.

Your task is to search the viewed scene and to decide whether a target is present or absent as rapidly as you can. A rapid response is essential in order to avoid detection and exposure to enemy fire. Use as little of the available 30 second search time as feasible to assure the speed of your decision as to whether the target is present or absent. An auditory signal will be presented after 15 and 25 seconds have elapsed to alert you to your increasing jeopardy.

These instructions in the order shown should fall from the left to the right portion of a ROC curve, since the accuracy instructions will presumably lead to less false alarms than the speed instructions, with the false alarms for the neutral instruction falling somewhere between them.

Two levels of target-to-background contrast, the second independent variable, were originally selected to represent those levels typically used in field studies. In such studies the levels are higher than those for laboratory studies, with higher margins for error, due to the problem of controlling target contrast under field conditions. The two levels selected were 35% and 45%. A 10% difference was used, since contrast differences as small as 5% can be discriminated in target acquisition studies. When it became apparent during the experiment that the contrast levels of 35% and 45% were not leading to response differences, a second experiment was added. This experiment used contrast levels of 14% and 17%, which are values typically used in laboratory studies. These values were achieved by simply reducing the initial calibrated light levels emitted from the projectors, as described in Chapter IV. The intent was to provide a comparison to the earlier levels, rather than to determine the performance difference between the 14% and 17% levels. Moreover, the difference between these two levels was smaller than the reliability of the equipment, as described in Chapter IV.

Dependent Variables. Reaction time and frequency of hits are the typical dependent measures of a target acquisition experiment. Because of the signal detection procedure, these measures will be collected with respect to the following four response categories (as described in

Appendix A): (a) hits; (b) misses; (c) false alarms; and (d) correct rejections. As a result, the study will involve eight dependent measures. While the statistical procedures of signal detection theory use only the hit and false alarm rate, the data for all of the response categories will be analyzed by conventional means.

Latin Square Design

Because of the number of trials required for each contrast level (30 scenes with a target and 30 scenes without a target), the two contrast levels were divided in half in order to reduce the number of trials required for any single experimental block. This led to the development of a 4 x 4 Greco-Latin square design where each of the resulting four contrast conditions was to be paired (crossed) with each set of four different background conditions. During the preparation of the stimulus materials, however, it became evident that this requirement could not be readily met. It was necessary, as a result, to pair each of the four contrast conditions with only one set of backgrounds. In effect, 120 different backgrounds were uniquely associated with each of the 120 experimental stimuli (i.e., 60 scenes with a target and 60 scenes without a target), that were presented to each observer. The resulting design, as a result, could be considered as a modified Latin square since contrast is nested (rather than crossed) with background. The original design was patterned after plan 13 in Winer (1971). This happened to be a modification of plan 9 which was finally used with the change noted above. This design is illustrated in Figure 5. The five experimental factors associated with this design are described below.

Instruction. As noted earlier, three sets of instruction were used. The same Latin square was repeated for each of these instructional sets (i.e., instruction was not distributed as a condition within the Latin square).

Contrast. Although only two contrast levels were involved in each experiment, they were distributed as four conditions within the Latin square. Each condition was nested with a specific group of background scenes.

Target Background. As discussed earlier, a different background scene was used for each target and nontarget presentation in order to avoid influencing the observer's responses due to prior familiarization with the scene. The background scenes were randomly divided into four groups, with one group being assigned to one of the four contrast conditions. These combinations led to four different experimental conditions.

Order. This refers to the counterbalancing of each of the four experimental conditions (contrast and background combination).

Trials. This refers to the numerical sequence in which the experimental conditions were presented to the test participants.

	Subjects	Trials 1	2	3	4
G_1	1, 2, 3	C_1 B_1	C_1 B_2	C_2 B_3	C_2 B_4
G_2	4, 5, 6	C_2 B_4	C_2 B_3	C_1 B_2	C_1 B_1
G_3	7, 8, 9	C_2 B_3	C_1 B_1	C_2 B_4	C_1 B_2
G_4	10, 11, 12	C_1 B_2	C_2 B_4	C_1 B_1	C_2 B_3

I = Instructions with three levels

C = Contrast
C_1 = high contrast, C_2 = low contrast

B = Background arranged into four blocks, with contrast nested

G = Order (counter balance arrangement of blocks)

T = Trials (fixed experimental sequence)

Figure 5. Modified Latin Square.

Test Participants

Twelve different subjects were used for each instructional set, for a total of 36 subjects. This number of subjects, together with the selection procedures and matching procedures employed (described in the following section) should minimize and control for the effect of subject differences between instructional sets.

Experienced Army helicopter pilots were used as the test participants. The pilots were selected to meet the following minimum requirements:

1. 500 hours flying experience
2. Experience in target acquisition
3. Normal visual acuity (20/20)
4. Normal peripheral vision (120^{o})
5. Age between 21 and 45
6. Males.

Matching of Test Participants

The test participants were given 25 practice trials at the start of the experiment. These trials consisted of typical target scenes, with a target in each scene. The target contrast levels were started at 100% levels and were gradually reduced to the experimental levels. The observers were simply instructed ". . . to search the viewed scene and to signal when you have located the target."

The reaction times for the last 10 of the practice trials were recorded for matching purposes. Only the mean reaction time for correct hits, however, were used for matching purposes. On the basis of this score, the observers were assigned to one of the three instructional groups depending upon the mean score of the observers already assigned. The first subjects were randomly assigned, with the following subjects being sorted depending upon the average value for an instructional group at that time. An observer with a relatively fast reaction time, for example, was assigned to the instructional group with the slowest average reaction time. In this manner, the average reaction times of each instructional group were equated. A one-way analysis of variance confirmed the lack of a significant difference between the data of the subjects assigned to each instructional group. Had such a difference occurred, observers with extreme scores (either by ranking or comparison to the mean score) would have been removed and replaced with new observers. Fortunately, this was not necessary. The only problem with this procedure was the unequal number of hits between the test participants, which in some cases ranged from as few as one to ten. The specific instructions given prior to the practice trials are contained in Appendix B.

Experimental Procedure

At the initiation of the experiment, the observers were informed that the purpose of the experiment was to collect target acquisition performance data relative to targets of varying contrast levels. They were not informed that different participants would be receiving different instructions. They were also briefed by means of enlarged photographs on the type of background they would see, and the fact that approximately 50% of the scenes would have targets. This latter statement, however, was omitted in the second experiment since some aviators apparently kept count of the number of targets they had found. Anonymity of their results was promised.

The general instructions given to the test participants at this time can be seen in Appendix B. In this and every subsequent case, the instructions were read to the test participant by the experimenter. The test participant, however, was also given a copy for his review while the instructions were being read to him.

One observer was tested at a time, in either a morning or noon session. Each session, including matching and familiarization trials, lasted approximately 3 to 4 hours for each participant. Two observers were tested each day.

After the target acquisition trials for matching purposes as described above, the observers were given familiarization trials prior to the start of formal data collection. The familiarization trials introduced several new considerations: (a) practice under the assigned instructional set; (b) feedback on whether the observer's response was correct or incorrect (when necessary the correct location of the target was pointed out); and (c) the use of the experimental levels of target contrast. Twenty trials were presented (10 with target and 10 without). The observers' responses were recorded but not analyzed. The experimental instructions for the assigned instructional set were used for these trials. These instructions can be seen in Appendix B.

As noted earlier, each of the subsequent experimental conditions had 30 scenes (15 with target and 15 without target). A 5- to 10-minute rest period was presented between each of these conditions. In addition, the instructions were repeated before the beginning of each condition, and repeated after every five trials within a condition (e.g., ". . . be as fast as you can"). Instructions were repeated in this manner to reinforce and sustain the instructional set of each participant.

At the end of the experimental trials, the participants were debriefed with regard to their performance and the goals of the study. The sequence of the above events can be summarized as follows:

- Pre-briefing
  - experimental aims
  - target areas
  - type of target
  - probability of target present
- Subject matching:
  - 25 trials
- Rest period
- Familiarization:
  - 20 trials
- Rest period
- Instructional set--one experimental condition or 30 trials
- Rest period
- Three additional experimental conditions and rest periods
- Debriefing

The specific operating procedures are described in Chapter IV.

CHAPTER IV. APPARATUS

Target and Background Projectors

Two carousel type 35mm slide projectors with identical 4:1 zoom lenses coupled to a variable speed motor were used for the independent projection of the target image and background scene. As a result of this arrangement, the stimuli could be presented at either a fixed slant range as in a helicopter pop-up maneuver, or dynamically as in an attack helicopter with a closing slant range. The projectors were securely mounted on an azimuth-elevation base run by two operator control knobs. The target projector had a variable density optical wedge placed in front of its lens, to permit the variation of target brightness. Both projectors were boresighted on the center of a 4 x 4 foot rear projection screen. The boresight projection could be changed to a different position on the screen by means of the azimuth and elevation controls. The maximum excursion of the boresight depended upon the zoom position of the lens (+1 foot at 1X magnification; +8½ feet at 4X magnification).

The expected system performance is shown in Figure 6, in which target image size on the screen is plotted against simulated target range, for several zoom scales. Control of lens accuracies and limitations of the photographic imagery brackets a useful range of 500 to 8000 feet. Within these simulated ranges, the optical resolution is better than the visual resolution of the human eye.

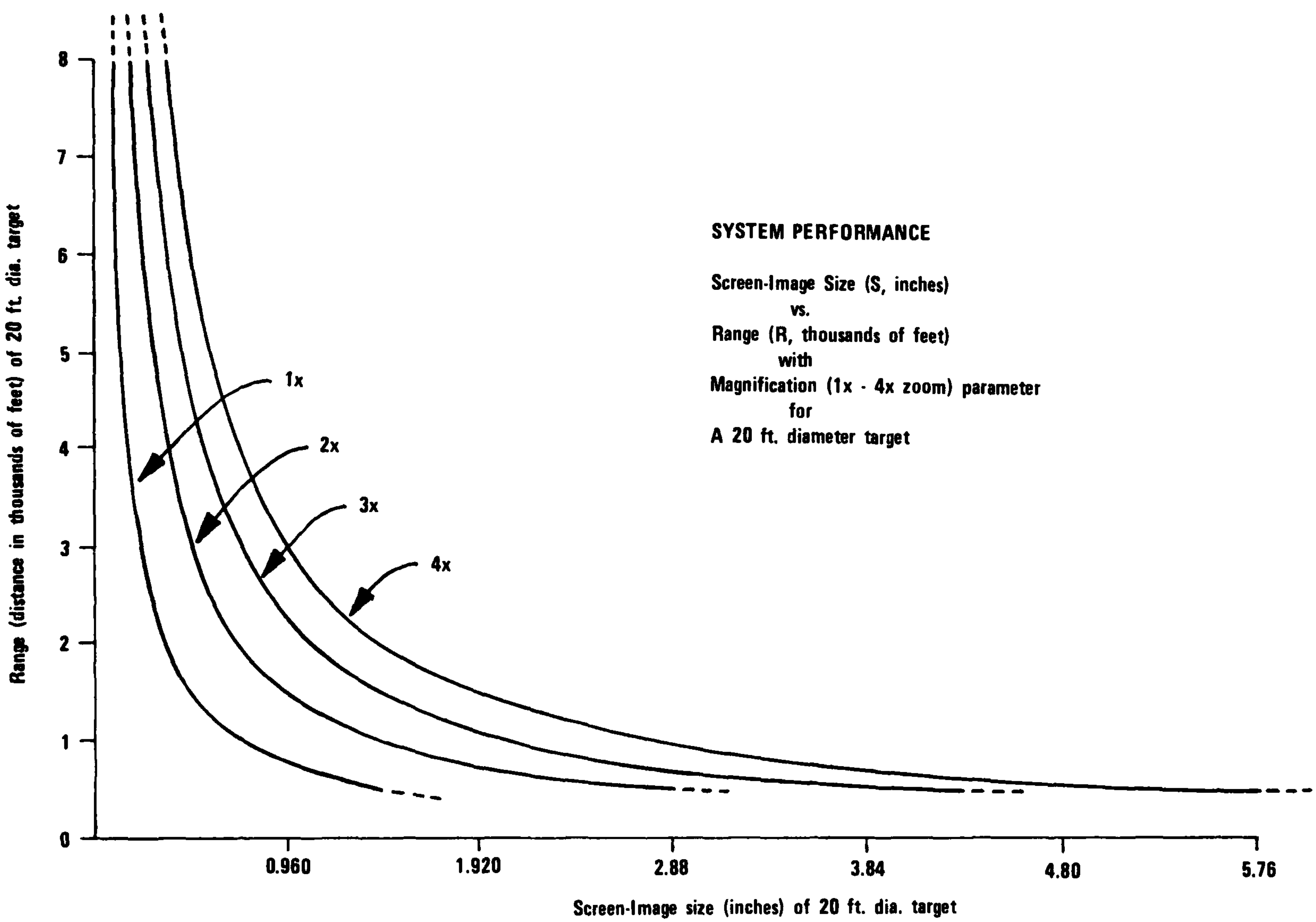

Figure 6. Screen imagery size vs. range to target.

The projectors were used with 1200 watt bulbs at a distance of 15 feet from the rear projection screen. At this distance the screen brightness was 120 foot lamberts, which reduced to approximately 3 foot lamberts when the stimulus materials (slides) were projected. Target luminance was considerably brighter depending upon the wedge setting.

Matrix Projector and Process Control System

A regular carousel projector was used to display a grid of 64 numbered squares on the display screen. The matrix would come on at the moment the observer pressed his detect button, at which time he would select the matrix quadrant number closest to the location where he saw the target. It would remain on until the next background scene was presented. Its light output was adjusted to present the same light level as the background scene, in order to maintain the visual light adaptation of the observer's eyes. The matrix projector was located halfway between the main projector and the display screen.

The targets were placed so that they would not coincide with the position of the matrix number when displayed. During the pilot studies, the target locations had been placed to be coincident with the matrix numbers. It was discovered that the observers realized this, and would change their confidence level if the suspected target did not coincide with the number.

A small process control system (Automated Data System 1800E) was used to control the experimental procedures, and to record the observer's responses. It cycled the slide tray in the background projector, opened and closed the shutters of the three projectors, allowed a 30-second exposure time, activated the tone generator and recorded the responses of the observers. The specific sequence and interaction of operator and computer tasks are described later in this chapter.

Display Room

The scenes were projected on a 4 x 4' 3M rear projection screen which was mounted between the projection room and the display room. For the present study, the screen was masked to a 2 x 2' square, with the subject's eye position placed at 20" from the screen. This provided a visual field of view of 50°.

A table with an adjustable chin rest was placed between the observer's chair and the screen. The chin rest was set to maintain a visual line of sight to the center of the screen at a 20" viewing distance. The height of the observer's chair was adjustable for personal comfort.

The response panel was placed on the table, near the left hand of the observer. The panel consisted of three rows of labeled response buttons. The detect button was placed at the bottom center portion of the panel. The middle row consisted of a series of 10 buttons for the indication of target location. The top row of buttons was used for entering the confidence level of the response. A second generator was placed on the floor near the table. This provided the 15 and 25-second warning tones to the observer.

A separate room served as a reception area and briefing room for the aviators. It had mounted photographs of the scenes to help acquaint them with their visual task. The projection room and display room were entered by different doors from this room. A layout of the laboratory is shown in Figure 7.

Stimulus Materials

The stimulus materials (photographs) were taken on the three-dimensional terrain table in the Guidance Development Center (GDC) of Martin Marietta. This table is a 40' x 40', 600:1 scale model of typical European terrain. It represents a simulated 4.5 x 4.5 square mile area. Utilization of this terrain table for the visual scene permitted: (a) the control of the desired visual perspective from a helicopter; (b) the control of ambient lighting conditions; and (c) the control of the desired optical geometry (i.e., the FOV of the displayed scene). At the slant ranges of interest, there was no loss of perceived visual fidelity in the features of the displayed scenes due to the normal loss of detail in images of decreasing visual angle.

Positive rather than negative slides were prepared to permit the projection of a negative rather than a positive black and white scene. This was done to simulate an infrared scene which would be consistent with the negative contrast of the independently projected tank. Since the tank was lighter than its background, it would have few competing objects which were comparable to it, in a normal black and white scene. By simulating an infrared scene, trees, rocks, and other dark objects became white and provided a set of competing objects for search purposes. Targets are usually darker than their background in the real world, although the opposite is not infrequent (e.g., tanks in front of darker trees). Studies have shown that psychophysical data relationships are the same for a given contrast level whether darker or lighter than its background.

Aviators who had experience with infrared displays felt that the simulated scenes were quite realistic. Target acquisition performance with infrared sensors is also an important operational problem for the Army. A "positive" scene, with a dark tank, could be simulated by videotaping the projected scene and displaying it on a television monitor with the polarity of the signal reversed. It is anticipated that there would

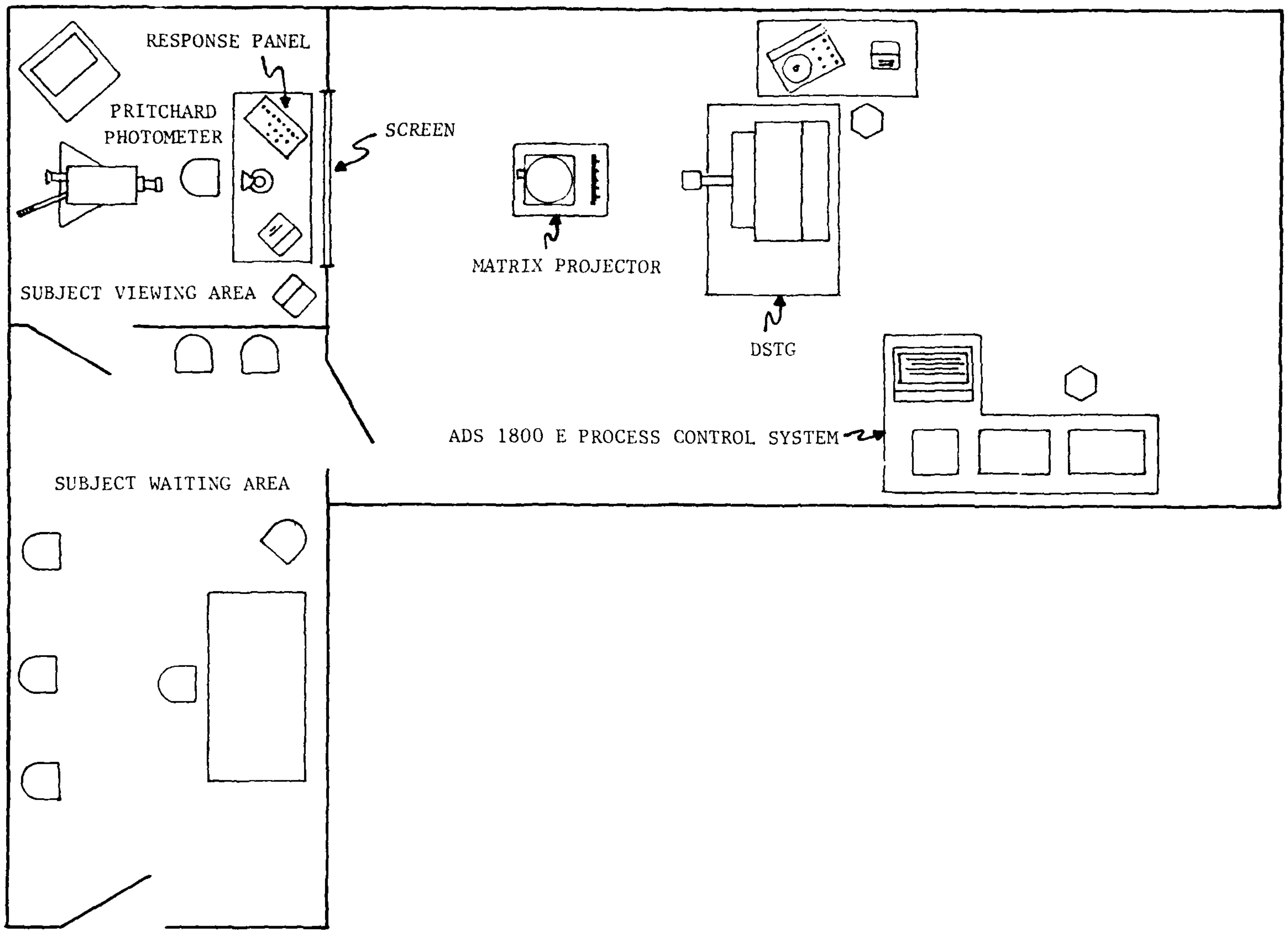

Figure 7. Layout of research laboratory.

be little if any change in performance between the use of "negative" and "positive" scenes, so long as all other conditions were held constant.

The only distortion from a true infrared scene was the uniform brightness of the simulated tank, instead of varying "hot spots." The original tank silhouettes had "hot spots." It was difficult, however, to measure contrast values on these tanks. As a result, a uniform silhouette was used to assure reliability of contrast control.

A 2 x 2 inch polished glass, with an "optical-cross" in its center, was used for preparation of the slides. The negatives were 4 x 5 inches in size. A spot was picked on each negative for the location of a tank. This included places along the edge of trees, in open fields, near roads, etc. The type of location was varied to avoid creating a special search strategy in the observers. The "optical-cross" was placed on the selected spot and a 2 x 2 inch portion of the negative was cut out. As a result, the selected location for the tank was now in the center of the slide. The slide was mounted between glass and placed in aluminum frames. A light table, lint-free gloves, and other aids were used to assure a dust-free and clean slide.

Preparation of the tank targets was accomplished using a shadow box technique. The tank model was supported on a vertical rod (at the rear of the model). It was illuminated by a pair of floodlights placed at 45^{o} to model. The room in back of the model was dark. Thus, when the picture was taken, the model appeared to be suspended in clear space (clear background). When this negative was printed, the model appeared in its natural tones, completely masked by a black background. This was essential to get no spillover from the target onto the background slide. The size of the tank on the negative was .013 inches. Six to eight different tank targets and positions were evaluated. A side profile was selected. The target slide was left inside the slide projector, whereas the background slides were kept in and cycled from a slide tray.

As mentioned in the preceding section, the target was independently projected. As a result, the background and target lenses were boresighted to the same spot on the screen. For this reason, the projected target would fall in the center of the background scene. The projected background scene was larger than the display screen depending upon the magnification of the lens. This permitted the simultaneous slewing of the target and background scene, to place the target in any desired position on the display screen. In this respect, targets were randomly located over the surface of the display, except dead center at the subject's eye position. During the pilot studies, it became apparent that targets in the center of the screen were found almost immediately at the onset of the scene, due to the fixation of the eye at this spot.

Over 200 background slides were prepared. One hundred twenty (120) of the best slides were selected for the experiment, with 45 slides selected for the practice and familiarization trials. The

finished slides were selected relative to the clarity and cleanliness of the displayed scene, and the final "projected" location of the target (e.g., to assure that the targets did not fall in the trees rather than along the edge of trees). The background scenes were randomly assigned to each experimental condition, with targets randomly assigned within each condition so that 15 scenes would be displayed with a target and 15 scenes without a target.

The slides for each experimental condition were placed in a separate slide tray, including those for the practice and familiarization slides. The appropriate slide tray was simply used for the desired experimental condition. For each slide position in a tray, the following information was recorded for the use by the experimenter when adjusting the required controls:

- target present or absent
- wedge setting for desired contrast value
- correct matrix location for target.

Establishment of Contrast Values and Calibration of Equipment

Target-to-background contrast was determined by the following formula:

$$\text{contrast} = \frac{DL}{LB}$$

DL = light difference between the background and target
LB = light value of background.

A Pritchard photometer was used to measure the light values of the target and its background. Each reading was taken at the eye level and viewing angle of the observer relative to the target location. This was necessary to compensate for the peculiar light distribution properties of a backlighted screen, such as light fall-off at the edges and the bend angles of the light rays. The light value used for the background was an average of four readings around the outside of the target, which were taken with a 6-minute aperture. The maximum obtainable value for the target was obtained by slewing the 1-minute aperture of the photometer within the target. The desired target-to-background contrast was obtained by increasing or decreasing the light intensity of the target by means of the optical wedge. The wedge setting associated with the desired contrast value was recorded.

To assure the reliability and repeatability of the contrast measurements, the light values of the target and background projectors were adjusted to the same value each day, at a fixed wedge setting. The intensity of the light from each projector was controlled by means of a Variac placed in the power line of each projector. The contrast values of all of the targets could be changed, without adjustment of the wedge

values, by simply changing the initial set-up value of the target projector by means of the Variac. This permitted implementation of the second experiment, without the tedious requirement to recalculate the values of each target and background slide, by simply dropping the initial calibration value by the required percentage.

The following factors could affect the reliability of the calibrated target-to-background contrast level:

- recycling of the background tray

  The target could fall on a slightly different place in the background, due to the repositioning of the background slide into the projector each time it is presented.

- reliability of the person taking the photometer readings

  Variability of photometer readings occur due to individual differences in the set-up and use of the photometer.

- wedge setting

  The operator positions the wedge to that value associated with each contrast level. It is difficult to return to the same location each time in a precise manner due to visual parallax, as well as motor coordination.

Repeated measurements indicated that the same contrast values could be achieved within 5% of the desired value.

Each day the following equipment set-up, calibration, and control procedures were followed:

1. Calibration of projector light values, including those for the target, background, and matrix.

2. Alignment and boresight of target and background projectors to the screen.

3. Focus of target and background projector.

4. Lens setting. Target and background sizes were a function of the lens focal length. The required values were maintained.

5. Alignment of matrix to screen.

6. Position of chin rest to assure a constant eye level.

Operating Procedures

The equipment was controlled by means of the process control system, as well as operator and observer actions. The sequence of actions was as follows:

1. The operator positioned the slide tray for each experimental condition (30 scenes).

2. The operator set the wedge value and adjusted the equipment for the target location of each scene by using the elevation and azimuth controls. If no target was to be presented, the wedge was set at its darkest setting to occlude the target.

3. The operator pressed a start button which activated the process control system (or computer).

4. The computer shut off the matrix, cycled the background tray, opened the shutters of each lens, and started the timer.

5. The computer allowed a 30-second exposure time unless the observer responded sooner. It also activated the 15 and 25-second warning tone.

6. If 30 seconds had not elapsed, and the subject made a decision, he pressed the detect button.

7. If 30 seconds had elapsed, or the observer had pressed the detect button, the computer stopped the timer, closed the shutters of the projectors, and opened the shutter of the matrix.

8. The observer entered a target location and his confidence rating. If 30 seconds had elapsed without a response, the observer was asked to guess (see Appendix B).

9. The computer printed out the observer's response time, confidence level, and target location, in addition to the other information shown in Table 1.

10. If all observer tasks were correctly performed, the computer released an interlock which permitted the operator to start the next sequence.

CHAPTER V. RESULTS

Treatment of Data

The data for each subject were recorded by a data processor in a format which would facilitate key punching on to IBM cards. This format is illustrated in Table 1. The first column in this table lists the

TABLE 1

DATA COLLECTION FORMAT

TRIAL NO.	TAR OR BAC	REAC TIME	LOC	C/I	CONF	SUB = 43
1 D	0	28325	0	1	1	
2 D	1	12145	49	1	4	
3 D	1	20210	63	1	4	
4 D	0	27595	0	1	1	
5 D	0	28717	0	1	1	
6 D	1	5717	23	1	4	
7 D	0	29393	0	1	1	
8 D	0	29050	0	1	1	
9 D	1	19201	11	1	4	
10 D	0	28058	0	1	2	
11 D	0	29303	0	1	1	
12 D	1	28658	0	0	2	
13 D	0	29955	0	1	1	
14 D	0	29936	0	1	1	
15 D	0	30000	0	1	1	
16 D	1	9274	17	1	4	
17 D	1	15502	13	1	4	
18 D	1	4049	31	1	4	
19 D	0	28318	0	1	1	
20 D	1	13783	49	1	4	
21 D	1	27801	0	0	2	
22 D	1	17419	51	1	4	
23 D	1	8351	59	0	4	
24 D	0	28062	0	1	1	
25 D	0	27565	0	1	1	
26 D	1	10581	53	1	4	
27 D	1	7103	58	1	4	
28 D	0	28259	0	1	1	
29 D	1	10412	27	1	4	
30 D	0	28385	0	1	2	

trial number. Adjacent to this number is the alphabetical indication of the particular experimental block being presented (A, B, C, D). The second column indicates whether a target is present in the scene (1), or whether the target is absent (0). The third column lists the subject's reaction time to one-thousand part of a second (a decimal point is not used). The fourth column lists the target location entered by the subject. A zero is entered if the subject decides the target was absent. This entry is immediately followed by an indication of whether the subject's response was correct (1) or wrong (0). The last column lists his confidence level for the decision made. After keypunching, the data were transferred to magnetic tape. For each of the subsequent data analyses, a FORTRAN program was written to extract the required data in the requisite format for the analyses.

In order to obtain the desired number of 36 subjects, with 12 in each instructional group, data were collected for 43 aviators in Experiment I. Seven subjects had no false alarms. They were omitted, since false alarms are necessary for the calculation of signal detection parameters. Data were collected for 36 aviators in Experiment II. The data for the last 12, however, were obtained after the Pritchard photometer used for daily calibration became inoperative. It was repaired by a staff engineer without the benefit of a factory calibration standard. The light levels resulting from the last calibrated equipment settings were used as a standard. These values, however, could have drifted from their measured values. Since the results of the last 12 subjects appeared to be superior to the results of the first 24 subjects, a two-way analysis of variance (subject x instruction) was used to evaluate the results. The results are shown in Tables 2 and 3 for the reaction time and frequency of hits, respectively. As can be seen in these two tables, subject differences are significantly different. The same pattern of results was obtained for an analysis of the reaction time and frequency of false alarms. As a result, the data of the last 12 subjects in Experiment II were excluded from any additional analysis.

For the following analyses, each subject's reaction time was converted to its log value in order to normalize the effects of positive skewness introduced by the 30-second exposure time. A log transformation rather than a reciprocal was used since it provides greater uniformity of variance. False alarms that occurred during the target trials were combined with the false alarms that occurred in the nontarget trials. This aspect is discussed more fully in Chapter III, and in the following analysis of the signal detection parameters.

As discussed in Chapter III, subjects were assigned to their instructional groups based on their reaction time for their hits on the last 10 of the 25 practice trials. A one-way analysis of variance was conducted on the mean of these scores for each group of subjects in each of the instructional sets. The analysis was conducted for the 36 subjects in Experiment I and the remaining 24 subjects in Experiment II. The data are shown in Tables 4 and 5, for Experiments I and II, respectively. By inspection of these tables, it is apparent that no significant

TABLE 2

COMPARISON OF FIRST 24 AND LAST 12 SUBJECTS OF EXPERIMENT II:
ANALYSIS OF VARIANCE FOR REACTION TIMES OF HITS

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	.05	2	.02	1.57
B. SUBJECT GROUPS	.32	1	.32	20.80**
A X B	.06	2	.03	2.03
WITHIN CELLS	.46	30	.02	
TOTAL	.89	35		

**p = .01

TABLE 3

COMPARISON OF FIRST 24 AND LAST 12 SUBJECTS OF EXPERIMENT II:
ANALYSIS OF VARIANCE FOR FREQUENCIES OF HITS

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	733.58	2	366.79	5.11*
B. SUBJECT GROUPS	1605.56	1	1605.56	22.36**
A X B	10.03	2	5.01	.07
WITHIN CELLS	2154.25	30	71.81	
TOTAL	4503.42	35		

*p = .05
**p = .01

TABLE 4

EVALUATION OF SUBJECT MATCHING IN EXPERIMENT I:
ANALYSIS OF VARIANCE FOR REACTION TIMES OF HITS

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
INSTRUCTION	.0036	2	.0018	.04
WITHIN CELLS	1.6402	33	.0497	
TOTAL	1.6438	35		

TABLE 5

EVALUATION OF SUBJECT MATCHING IN EXPERIMENT II:
ANALYSIS OF VARIANCE FOR REACTION TIMES OF HITS

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
INSTRUCTION	.0028	2	.0014	.03
WITHIN CELLS	1.0938	21	.0521	
TOTAL	1.0966	23		

differences existed between the scores of the subjects assigned to each instructional group. It can be concluded consequently that the matching procedure was successful.

Analyses of Reaction Time and Frequency of Responses

The conventional target acquisition dependent measures are usually the frequency of target acquisition (hits) and their reaction time. The use of the signal detection paradigm, however, resulted in eight dependent measures. This is due to the recording of hits and misses for the target trials, and the recording of false alarms and correct rejects for the nontarget trials. In view of the Latin Square design used, it appeared necessary as a result to conduct 16 Latin Square analyses for each of the eight dependent variables of each experiment. The purpose of such an analysis was to evaluate the effect of the experimental procedures (order, trials, and backgrounds), in addition to the primary independent variables of instruction and contrast.

Consideration was given to reducing the number of dependent variables, by treating response type (hit, miss, false alarm, and correct reject) as an independent variable. Several disadvantages, however, were found to be associated with this approach. First, the response categories are not really true levels of a factor, but are basically different dependent variables. In addition, a predetermined interaction exists between the frequency of hits and misses, and between false alarms and correct rejects. There was also the problem of unequal occurrences of hits and correct rejects when compared to misses and false alarms. As a result of these considerations, this approach was not adopted.

Consideration was also given to treating the frequency of hits and false alarms as a percentage value. Misses and correct rejects would then not have to be analyzed separately, since their results would be the complimentary percentage. However, false alarms occurred in the target as well as nontarget trials. The former were added to the false alarm totals of the nontarget trials, for reasons discussed elsewhere. As a result, the appropriate denominator for each response category is no longer clear cut. As a result, this approach was also not taken.

Two Latin Square analyses were conducted for the reaction time and frequency of hits for Experiment I. As a result of these analyses, it was determined that the effects of order, trials, and background were not statistically significant (with one minor exception for trial effects associated with reaction time as discussed below). As a result, it seemed reasonable to assume that the effects of these variables would be negligible for the remaining dependent measures. In addition, it was found that the contrast values of 35% and 45% were not statistically significant. It was therefore reasonable to assume that the contrast values of 14% and 17% in Experiment II would also not be statistically significant, particularly since the difference in their values did not

exceed the reliability of the stimulus generating and calibration equipment. In view of the above considerations, it was considered feasible to combine the data of the two experiments for the conduct of a two-way analysis of variance (nonrepeated measures), where the combined contrasts of each experiment represented a single contrast level and where contrast became a between rather than a within factor. This design is shown in Table 6. This analysis procedure was applied to each of the eight dependent variables, and is described below in addition to the results of the two Latin Square analyses mentioned previously.

TABLE 6

TWO-WAY ANALYSIS OF VARIANCE FOR
CONTRAST AND INSTRUCTION

	Contrast	
Instruction	High	Low
Neutral	I	I
Speed	II	II
Accuracy	III	III

The results of the Latin Square analysis for the reaction time of hits are shown in Table 7 for Experiment I. As can be seen in this table, only instructions are significant at the .01 confidence level, and trial effects at the .05 confidence level. The mean log reaction time for trials in order of their sequence are as follows: .9189, .9108, .8664, and .9347. The subjects in this experiment speeded up in the third trial, probably due to increasing familiarization with the search procedures, but slowed down in the fourth trial probably due to fatigue. This variable was not found to be significant in the Latin Square analysis conducted for the frequency of hits (Table 9), which indirectly supports the interpretation for the facilitation and fatigue effect of the number of trials on response time. As discussed in Chapter III, the change from a Greco-Latin square to a Latin Square design resulted in a potential confounding effect between contrast and background. The results in Table 7, however, indicate that neither variable was significant when considered separately or together. Table 8 shows the results of a Newman-Keuls analysis on the reaction time means of the instructional variable. As can be seen in this table, the neutral and accuracy instruction have similar reaction times which

TABLE 7

LATIN SQUARE ANALYSIS FOR REACTION TIMES OF HITS: EXPERIMENT I

SOURCE OF VARIANCE	SS	df	MS	F
BETWEEN	3.7805	35		
INSTRUCTION	1.0816	2	.5408	6.7769**
ORDER = BLOCK	.7040	3	.2347	2.9411
ORDER x INSTRUCTION	.0786	6	.0131	0.1642
E 1	1.9163	24	.0798	
WITHIN SUBJECTS	1.1912	108		
TRIALS	.0925	3	.0308	2.7500*
BACKGROUND	.0118	3	.0039	0.3482
CONTRAST	.0037	1	.0037	0.9250
E 2 = BACKGROUND w CONTRAST	.0081	2	.0040	.357
RESIDUAL	.0563	6	.0094	0.8393
INSTRUCTION x TRIALS	.0467	6	.0078	0.6964
INSTRUCTION x BACKGROUND	.0374	6	.0062	0.5536
INSTRUCTION x CONTRAST	.0165	2	.0082	0.7321
INSTRUCTION x BACKGROUND w CONTRAST	.0209	4	.0052	0.4643
INSTRUCTION x RESIDUAL	.1405	12	.0117	1.0446
E 3	.8060	72	.0112	

**p = .01
*p = .05

were significantly slower than those for the speed group. This same pattern of results occurred when the same data for Experiments I and II were analyzed by the two-way analysis of variance as described later.

TABLE 8

NEWMAN-KEULS TEST OF REACTION TIME MEANS
FOR INSTRUCTION OF EXPERIMENT I

	Instruction			
Instruction	II	I	III	Means
II (Speed)	--	.1608*	.2004*	.7873
I (Neutral)		--	.0396	.9481
III (Accuracy)			--	.9877

*p = .05.

The results of the Latin Square analysis for the frequency of hits for Experiment I are shown in Table 9. The only significant effect occurs for the interaction of instruction x background with contrast. In addition to being a weak interaction, inspection of the associated mean values indicated that the results could be attributed to random events. Instructions are not significant with respect to frequency of hits as they were for reaction time. A significant main effect occurs, however, when the data of Experiments I and II are combined as described below.

As noted in the beginning of this discussion a decision was made, based on the above results, to treat the data of Experiments I and II in a single two-way analysis of variance for each of the eight dependent variables. The combined contrast levels of Experiment I represent high contrast and those of Experiment II represent low contrast. While these analyses and those for the signal detection parameters should have been conducted for unweighted means due to unequal cell entries, as a result of the loss of subjects, the computer programs that were used were based on weighted means. Separate calculations indicated, however, that there was little or negligible change between each approach. As a result, all of the subsequent analyses are based on weighted means. The log reaction time values, in the following tables for mean values, have been converted to their anti-log value (or geometric mean) for ease of interpretation. The results of these analyses are as follows:

TABLE 9

LATIN SQUARE ANALYSIS FOR FREQUENCIES
OF HITS: EXPERIMENT I

SOURCE OF VARIANCE	SS	df	MS	F
BETWEEN	817.0000	35		
INSTRUCTION	105.2916	2	52.6458	2.4391
ORDER	84.8333	3	28.2777	1.3101
ORDER x INSTRUCTION	108.8751	6	18.1458	0.8407
E 1	518.0000	24	21.5833	
WITHIN SUBJECTS	393.0000	108		
TRIALS	23.1667	3	7.7222	2.4314
BACKGROUND	17.16667	3	5.7222	1.8017
CONTRAST	11.1111	1	11.1111	3.6697
E 2 = BACKGROUND w CONTRAST	6.0556	2	3.0278	
RESIDUAL	28.3889	6	4.7314	1.4897
INSTRUCTION x TRIALS	8.0417	6	1.3402	.4219
INSTRUCTION x BACKGROUND	53.2084	6	8.8680	2.7922
INSTRUCTION x CONTRAST	10.1806	2	5.0903	1.6027
INSTRUCTION x BACKGROUND w				
CONTRAST	43.0278	4	10.7569	3.3870
INSTRUCTION x RESIDUAL	34.3607	12	2.8634	0.9016
E 3	228.6667	72	3.1759	

a. Reaction Time of Hits

The cell and combined means of the reaction times for hits for the contrast and instruction variables are shown in Table 10, with the results of the analysis of variance shown in Table 11. As can be seen in this latter table, the main effects for both contrast and instruction are significant. The data from Table 10 are plotted in Figure 8. It can be seen in this figure that the results of the accuracy and neutral instruction groups are equivalent, with each having a longer average reaction time than the speed instruction group. In this respect, a Newman-Keuls test of the row means in Table 10 indicated that the speed instructional group was significantly faster than the neutral and accuracy groups at the .01 confidence level.

b. Frequency of Hits

The cell and combined means of the frequency of hits for the contrast and instructional variables are shown in Table 12, with the results of the analysis of variance shown in Table 13. The data from Table 12 are plotted in Figure 9. As can be seen in Table 13, the results of the instruction and contrast variables are also significant. The significant finding for instruction unlike the results of the Latin Square analysis for Experiment I described previously, is due to the larger number of subjects available in this analysis. This is also evident by the fact that the Newmen-Keuls tests were generally significant for only the combined means. The pattern of results, however, for each instruction and contrast condition (cell values) is consistent, as can be seen in each of the figures of this section.

In Figure 9 it can be seen that the accuracy instruction resulted in a greater number of hits at both contrast levels, with the neutral instruction group having fewer hits similar to the results of the speed group. In this respect, a Newman-Keuls test of the row means indicates that the speed instructional group had significantly fewer hits than the accuracy group at the .01 confidence level. It is apparent from Figures 8 and 9 that the accuracy group took longer to make a response and got more hits than the speed group. The neutral group on the other hand, while taking as much time as the accuracy group to make a response, got fewer hits similar to the results of the speed group (although its results were not significantly different than those of the accuracy group).

c. Reaction Time of False Alarms

The cell and combined means of the reaction times for false alarms are shown in Table 14, with the results of the analysis of variance shown in Table 15. As can be seen in this latter table, only the instruction variable is significant for false alarms. The lack of significance for the contrast variable is not unexpected, since stimuli falsely selected as targets do not have a controlled contrast level.

TABLE 10

MEAN REACTION TIMES OF HITS

	CONTRAST			
INSTRUCTION	HIGH	LOW	*	ROW MEAN
NEUTRAL	8.92	11.00	*	9.96
SPEED	6.14	7.88	*	7.01
ACCURACY	9.58	10.98	*	10.28
COL MEAN	8.21	9.95	*	

TABLE 11

ANALYSIS OF VARIANCE TABLE FOR REACTION TIMES OF HITS

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	.33	2	.17	9.76**
B. CONTRAST	.11	1	.11	6.25**
A X B	.01	2	.00	.17
WITHIN CELLS	.92	54	.02	
TOTAL	1.37	59		

**p = .01

TABLE 12

MEAN FREQUENCIES OF HITS

	CONTRAST			
INSTRUCTION	HIGH	LOW	*	ROW MEAN
NEUTRAL	42.1667	33.8750	*	38.8500
SPEED	38.7500	29.8750	*	35.2000
ACCURACY	47.0833	40.2500	*	44.3500
COL MEAN	42.6667	34.6667	*	

TABLE 13

ANALYSIS OF VARIANCE TABLE FOR FREQUENCIES OF HITS

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	852.02	2	426.01	5.03**
B. CONTRAST	921.60	1	921.60	10.88**
A X B	10.62	2	5.31	.06
WITHIN CELLS	4572.08	54	84.67	
TOTAL	6356.32	59		

**p = .01

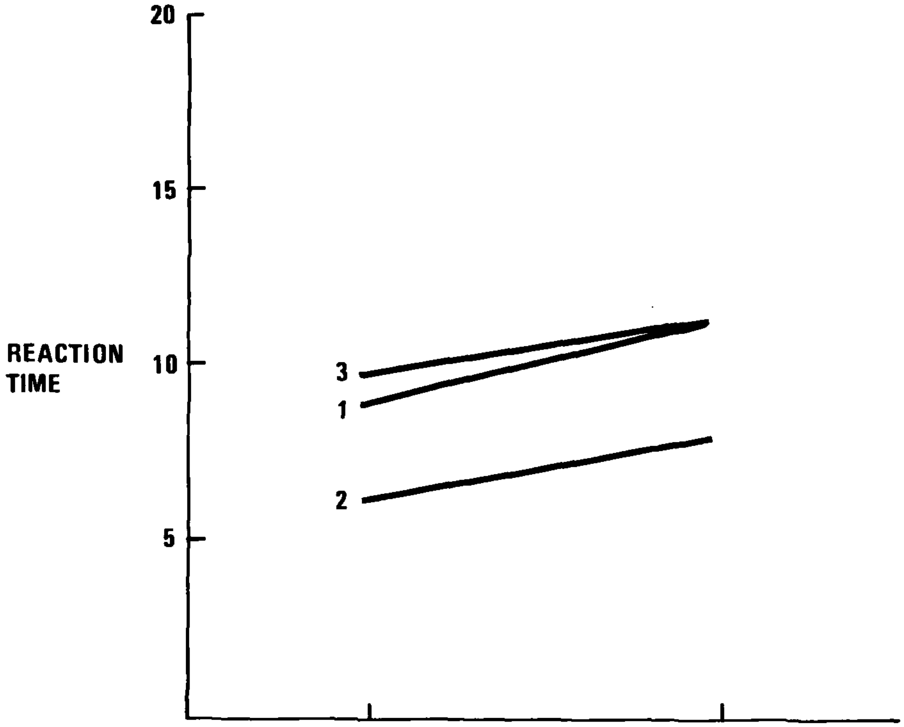

Figure 8. Reaction time of hits for instruction and contrast.

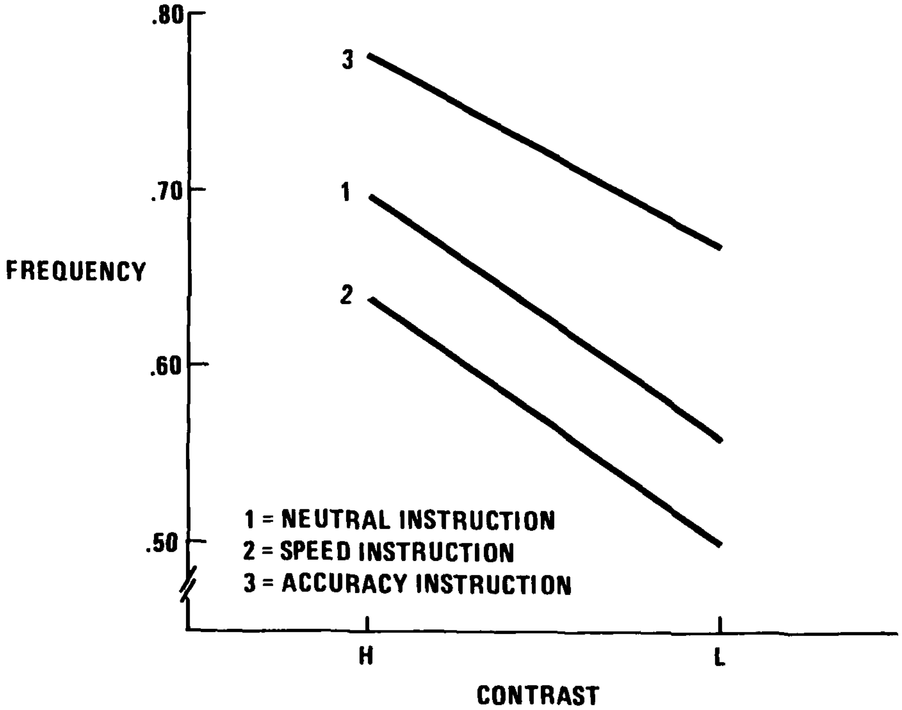

Figure 9. Frequency of hits for instruction and contrast.

TABLE 14

MEAN REACTION TIMES OF FALSE ALARMS

	CONTRAST			
INSTRUCTION	HIGH	LOW		ROW MEAN
NEUTRAL	23.11	25.27	*	24.19
SPEED	15.42	18.35	*	16.88
ACCURACY	26.51	26.05	*	26.28
COL MEAN	21.68	23.22	*	

TABLE 15

ANALYSIS OF VARIANCE TABLE FOR REACTION TIMES OF FALSE ALARMS

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	.39	2	.19	16.09**
B. CONTRAST	.02	1	.02	1.43
A X B	.02	2	.01	.66
WITHIN CELLS	.62	52	.01	
TOTAL	1.04	57		

**p = .01

The data shown in Table 14 is plotted in Figure 10. It can be seen in this figure that the results of the neutral and accuracy instruction groups are similar to each other, and that both are slower than the speed group. In this respect, the results are similar to those obtained for the reaction time of hits, as comparison of Figures 10 and 8 will indicate. However, the average response for the false alarms takes longer, indicating the increased uncertainty of the response. A Newman-Keuls test of the row means indicates that the reaction time of the speed group is also significantly faster than the results of the accuracy and neutral groups.

d. Frequency of False Alarms

The cell and combined means of the frequency of false alarms for the contrast and instruction variables are shown in Table 16, with the results of the analysis of variance shown in Table 17. Inspection of the latter table indicates that contrast as well as instruction is significant, in addition to a significant interaction between contrast and instruction. These relationships are illustrated in Figure 11. In this figure it can be seen that the number of false alarms increases greatly at low contrast for the neutral and speed instructional groups. This increase, however, does not occur for the accuracy instructional group. A Newman-Keuls test of the row means confirms that the accuracy instruction has significantly fewer false alarms than the speed and neutral groups at the .01 confidence level.

Thus, while the reaction time of the accuracy and neutral groups is significantly slower than the reaction time of the speed group for hits and false alarms, the accuracy group gets significantly more hits than the speed group and significantly fewer false alarms than the speed and neutral groups at low contrast. Hence, there is a significant trade-off of more hits and fewer false alarms versus time for the accuracy instructional group when compared to the speed group. In addition, while the neutral group responds as slowly as the accuracy group, it does not particularly benefit with an increase in hits, and has significantly more false alarms at low contrast.

e. Reaction Time of Misses

As noted earlier a miss occurs when the observer fails to find an existing target. The cell and combined means of the reaction times of misses for the contrast and instructional variables are shown in Table 18, with a summary of the results of the analyses of variance shown in Table 19. As can be seen in this latter table, both instruction and contrast are significant. The data of Table 17 are plotted in Figure 12. Once again, it can be seen that the results of the accuracy and neutral instructions are similar, and both are appreciably slower than the results of the speed instructional group. A Newman-Keuls test of the data in Table 18 indicates that the speed group is significantly faster than either the accuracy and neutral groups.

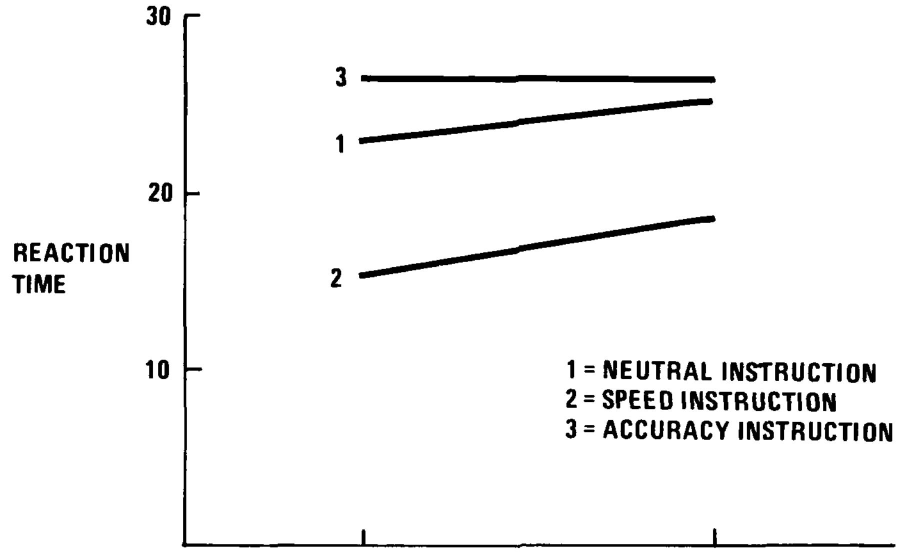

Figure 10. Reaction time of false alarms for instruction and contrast

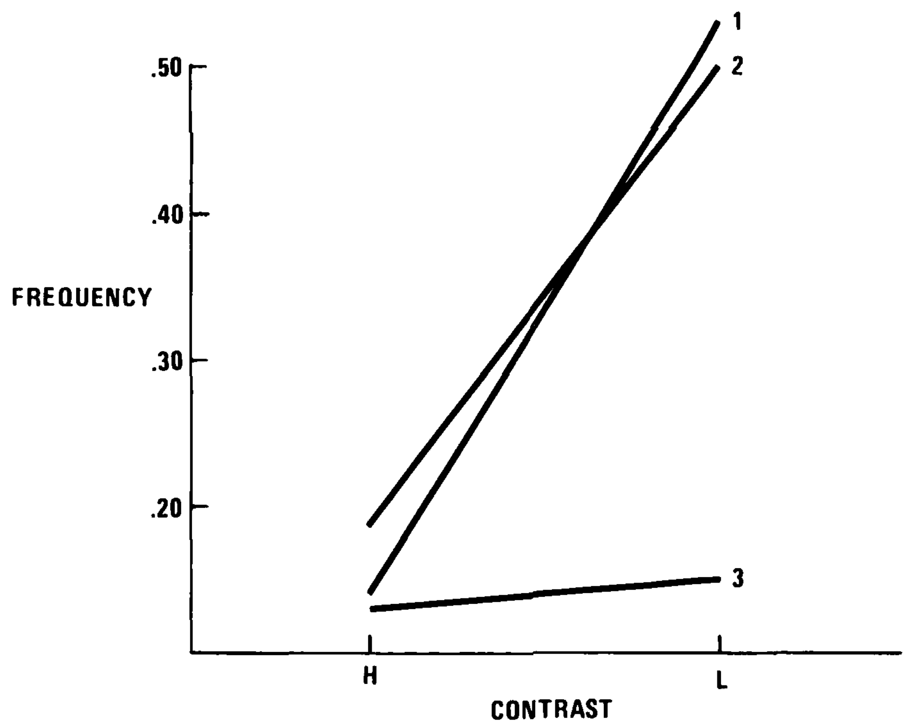

Figure 11. Frequency of false alarms for instruction and contrast.

TABLE 16

MEAN FREQUENCIES OF FALSE ALARMS

CONTRAST

INSTRUCTION	HIGH	LOW	ROW MEAN
NEUTRAL	8.4167	31.8750	17.8000
SPEED	11.5000	29.8750	18.8500
ACCURACY	8.0000	9.0000	8.4000
COL MEAN	9.3056	23.5833	

TABLE 17

ANALYSIS OF VARIANCE TABLE FOR FREQUENCIES OF FALSE ALARMS

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	1820.51	2	910.25	6.75**
B. CONTRAST	2935.51	1	2935.51	21.77**
A X B	1331.37	2	665.69	4.94*
WITHIN CELLS	7281.67	54	134.85	
TOTAL	13369.06	59		

**p = .01
*p = .05

TABLE 18

MEAN REACTION TIMES OF MISSES

	CONTRAST			
INSTRUCTION	HIGH	LOW		ROW MEAN
NEUTRAL	26.65	29.54	*	27.77
SPEED	17.64	22.11	*	19.30
ACCURACY	28.50	29.64	*	28.95
COL MEAN	23.75	26.84	*	

TABLE 19

ANALYSIS OF VARIANCE FOR REACTION TIMES OF MISSES

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	.33	2	.17	18.04**
B. CONTRAST	.04	1	.04	4.45*
A X B	.02	2	.01	.89
WITHIN CELLS	.50	54	.01	
TOTAL	.88	59		

**p = .01
*p = .05

These results and data relationships are identical to the results of reaction time for hits. Figures 8 and 12, in this respect, are nearly identical plots. The only difference in the data is that the reaction times for misses are slower. It appears that the differences due to instructional set were maintained in making the decision of no target.

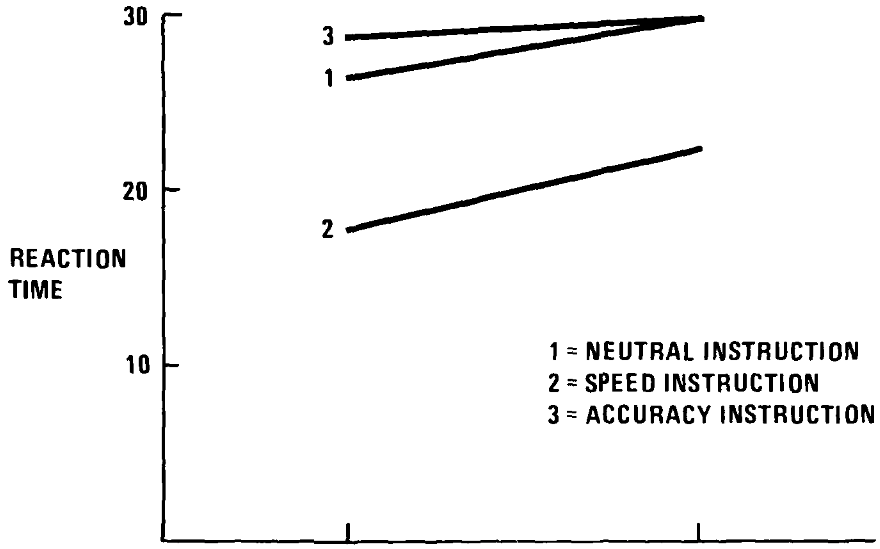

Figure 12. Reaction time of misses for instruction and contrast.

f. Frequency of Misses

The cell and combined means of the frequency of misses for the contrast and instruction variables are shown in Table 20, with a summary of the results of the analysis of variance shown in Table 21. As can be seen in the latter table, neither contrast nor instruction are significant, unlike the results for the frequency of hits. However, since the frequency of misses is a complement of the frequency of hits, insofar as each subject responded to a fixed number of target trials, the data should be an inverted image of the data plotted in Figure 9 for the frequency of hits. The results of Table 20 are plotted in Figure 13. With the exception of the results of the accuracy instruction at low contrast, the results do represent an inverted image of the results of Figure 9. The anomaly with respect to accuracy can be attributed to the fact that the results are not true complements since false alarms have been removed from the category of hits and added to the background only trials. In this respect, inspection of the data reveals that fewer false alarms of both types occurred for the accuracy group at low contrast. As a result, the overall relationship between hits and misses has been distorted among the instructional groups.

TABLE 20

MEAN FREQUENCIES OF MISSES

INSTRUCTION	CONTRAST HIGH	LOW		ROW MEAN
NEUTRAL	15.3333	16.3750	*	15.7500
SPEED	17.6667	19.0000	*	18.2000
ACCURACY	10.5000	17.0000	*	13.1000
COL MEAN	14.5000	17.4583	*	

TABLE 21

ANALYSIS OF VARIANCE TABLE FOR FREQUENCIES OF MISSES

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	202.12	2	101.06	1.60
B. CONTRAST	126.03	1	126.03	1.99
A X B	90.52	2	45.26	.72
WITHIN CELLS	3414.21	54	63.23	
TOTAL	3832.87	59		

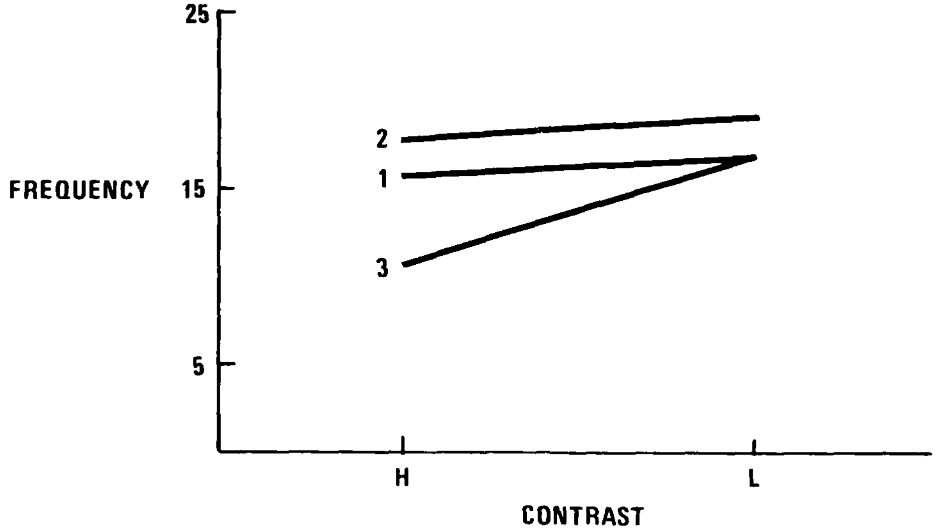

Figure 13. Frequency of misses for instruction and contrast.

g. Reaction Time for Correct Rejection

The cell and combined means of the reaction times for correct rejections for the contrast and instructional variables are shown in Table 22, with a summary of the results of the analysis of variance shown in Table 23. As can be seen in the latter table, instruction and contrast are both significant. The data of Table 22 are plotted in Figure 14. As in the case of reaction time for misses and hits, the data relationships in Figure 14 are nearly identical to those of reaction time of false alarms as plotted in Figure 9. Once again the responses for the accuracy and neutral instructions are similar and slower than the responses of the speed instruction. A Newman-Keuls test also indicates that the responses of the speed instructional group are significantly faster than those for the accuracy and neutral groups. Unlike the constant time difference found between the reaction times for hits and misses, the reaction times for false alarms and correct rejects are similar. They are also similar to reaction times for misses. While the miss and correct reject responses are similar in nature and unlike the decision for a false alarm, it would appear as a result of these findings that under uncertainty the subjects take approximately the same amount of time. The interesting result, however, is that the pattern of differences between the reaction times of instructional sets is maintained over each of the response categories, which indicates the pervasiveness of the instructional set of this study.

TABLE 22

MEAN REACTION TIMES OF CORRECT REJECTIONS

CONTRAST

INSTRUCTION	HIGH	LOW		ROW MEAN
NEUTRAL	26.56	29.85	*	27.83
SPEED	16.40	21.41	*	18.25
ACCURACY	28.37	29.78	*	28.92
COL MEAN	23.12	26.70	*	

TABLE 23

ANALYSIS OF VARIANCE TABLE FOR REACTION TIMES OF CORRECT REJECTIONS

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	.43	2	.22	24.78**
B. CONTRAST	.06	1	.06	6.43*
A X B	.02	2	.01	1.29
WITHIN CELLS	.47	54	.01	
TOTAL	.98	59		

**p = .01
*p = .05

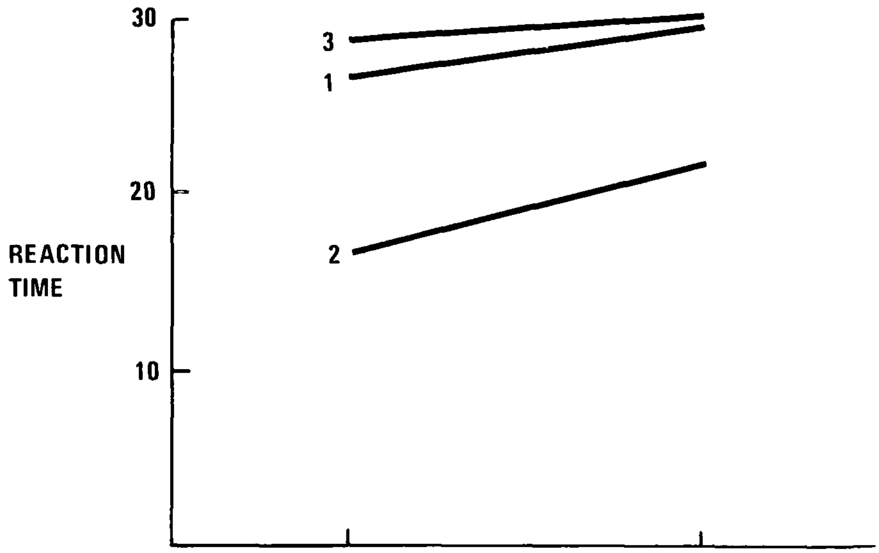

Figure 14. Reaction time of correct rejections for instruction and contrast.

h. Frequency of Correct Rejections

The cell and combined means of the frequency for correct rejects for the contrast and instructional variables are shown in Table 24, with a summary of the results of the analysis of variance shown in Table 25. As can be seen in the latter table, instructions and contrast are both significant, including a significant interaction between them. These results, as would be expected, are a complement of the results for the frequency of false alarms. This is evident in Figure 15, where the data relationships are an inverted image of those for Figure 11, including the interaction of the accuracy instruction with low contrast. Thus while the pattern of results for reaction times is similar across response categories, the frequency results for misses and correct rejects are essentially complements of the hits and false alarms as would be expected.

The following additional analyses were run to determine whether there were any effects introduced by the use of different experimenters in the collection of data, and the use of aviators who were on active and inactive flight status. Five experimenters were used to collect the data. This was necessary since each experimental session took approximately 4 hours and the fact that 79 aviators were tested. A two-way analysis of variance was conducted on instructional set and the data of subjects collected by each of the five experimenters. This approach was necessary to control for the effects of instructional set,

TABLE 24

MEAN FREQUENCIES OF CORRECT REJECTIONS

	CONTRAST			
INSTRUCTION	HIGH	LOW		ROW MEAN
NEUTRAL	54.0833	37.7500	*	47.5500
SPEED	52.0833	41.2500	*	47.7500
ACCURACY	54.1667	53.7500	*	54.0000
COL MEAN	53.4444	44.2500	*	

TABLE 25

ANALYSIS OF VARIANCE TABLE FOR FREQUENCIES OF CORRECT REJECTIONS

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	757.76	2	378.88	6.60**
B. CONTRAST	1217.34	1	1217.34	21.22**
A X B	627.36	2	313.68	5.47**
WITHIN CELLS	3098.00	54	57.37	
TOTAL	5700.46	59		

**p = .01

as they were not distributed evenly among the experimenters. The analysis was run for reaction time and frequency of hits and false alarms. While instruction was significant, no significant difference was found between experimenters. The results for the analysis of variance for reaction time and frequency of hits are shown in Tables 26 and 27, respectively.

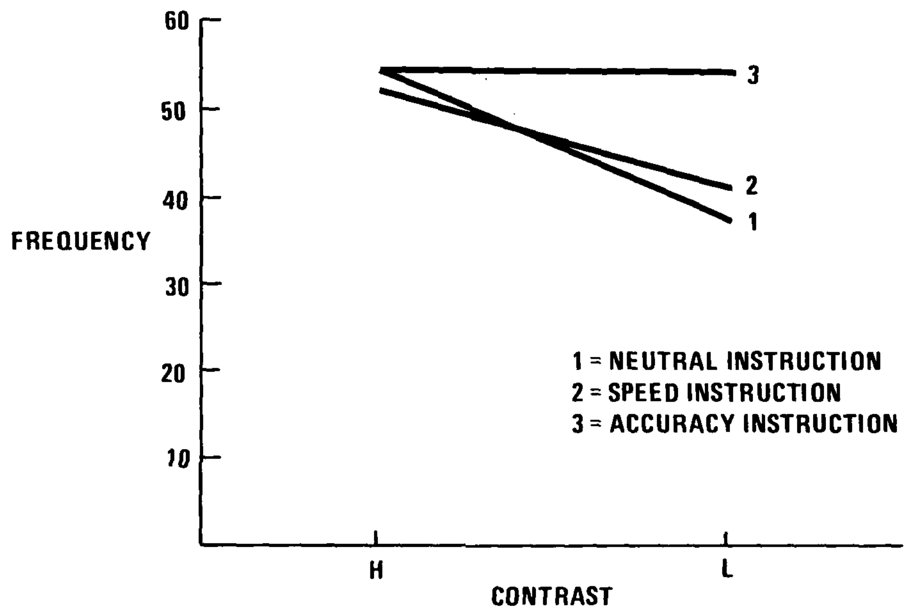

Figure 15. Frequency of correct rejections for instruction and contrast.

Rated Army aviators on active and inactive flight status were used as subjects, with 10 of the subjects in Experiments I and II being in the latter category. An analysis was also conducted on the data of these individuals to assure that performance differences were not a function of flight status. A two-way analysis of variance was conducted between flight status and instruction, since the latter was not evenly distributed among the active and inactive aviators. The analysis was conducted for reaction time and frequency of hits and false alarms. While the results of the instructional variable were similar to the basic analyses, no significant difference was found for flight status. The results of the analyses of variance for the reaction time and frequency of hits are shown in Tables 28 and 29.

TABLE 26

EVALUATION OF EXPERIMENTER EFFECTS:
ANALYSIS OF VARIANCE FOR REACTION TIME OF HITS

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	.40	2	.20	10.39**
B. EXPERIMENTERS	.04	4	.01	.49
A X B	.11	8	.01	.73
WITHIN CELLS	.83	43	.02	
TOTAL	1.37	47		

**p = .01

TABLE 27

EVALUATION OF EXPERIMENTER EFFECTS
ANALYSIS OF VARIANCE FOR FREQUENCIES OF HITS

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	655.74	2	327.87	4.35*
B. EXPERIMENTERS	144.34	4	36.08	.48
A X B	1360.80	8	170.10	2.26
WITHIN CELLS	3237.80	43	75.30	
TOTAL	5398.68	57		

*p = .05

TABLE 28

AVIATORS ON ACTIVE AND INACTIVE FLIGHT STATUS.
ANALYSIS OF VARIANCE FOR REACTION TIMES OF HITS

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	.34	2	.17	9.42**
B. AVIATORS	.05	1	.05	2.98
A X B	.01	2	.00	.22
WITHIN CELLS	.98	54	.02	
TOTAL	1.38	59		

**p = .01

TABLE 29

AVIATORS ON ACTIVE AND INACTIVE FLIGHT STATUS:
ANALYSIS OF VARIANCE FOR FREQUENCIES OF HITS

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	606.04	2	303.02	3.12
B. AVIATORS	1.14	1	1.14	.01
A X B	198.91	2	99.46	1.02
WITHIN CELLS	5242.72	54	97.09	
TOTAL	6048.81	59		

Signal Detection Analysis

The confidence ratings obtained for each subject represent the basic input data for the signal detection analysis. As described previously, the following confidence ratings were used during data collection:

4	Target--positively there
3	Target--probably there
2	No target--probably not there
1	No target--positively not there

The calculation of the number of hits (H) and false alarms (FA) derives directly from these confidence intervals. The raw data of each subject were arranged into the necessary format for the signal detection analysis. This simply involved tabulating the number of responses made to each confidence interval for the noise and the signal plus noise experimental conditions. Sixty responses were possible for each of these conditions for each subject. The statistical procedures for calculating each individual's signal detection parameters are described in Appendix C. The above summary input data, however, were analyzed by means of a computer program entitled, "Signal Detection Rating - Scale Analysis" (RSCORE). This program was prepared by D. Dorfman in 1969, modified by L. Beaver in 1972, and subsequently modified by L. Harvey in 1975 and 1977. A description of the program is contained in Appendix D.

Two preliminary analyses were run on the data of the first subject in the first experiment to resolve the following two issues:

(1) Contrast Levels

Contrasts of 35% and 45% were used in the first experiment and 14% and 17% in the second experiment. In the analyses reported earlier, the effects of contrast were found to be significant between experiments but not within experiments. It is possible, nevertheless, that significant differences could be found between the two contrast levels within experiments when analyzed by the signal detection parameters. For this reason the 35% and 45% data of subject (1) were analyzed by RSCORE. The obtained sensitivity measure (D(A)) was 1.84 and 1.55, respectively. This direction of the difference is opposite to what would be expected, as the 45% contrast should yield the higher sensitivity level. This apparent inconsistency could be due to several factors such as the lack of a main effect or due to the number of data points used. Thirty data points were used for each condition of noise and signal plus noise for each contrast level. As mentioned in Chapter III, 500 trials are not uncommon in signal detection experiments. Due to the lack of a main effect for contrast levels within experiments, the above discrepancy and the desire to increase the reliability of the data the contrast levels within each experiment were combined.

(2) False Alarms

The second consideration concerned the treatment of false alarms which occurred in the signal plus noise (target) trials in addition to those which occurred in the noise (nontarget) trials. As discussed in Chapter II, false alarms in the typical signal detection experiment can occur only in the noise trials. In the present experiment, the number of false alarms of each type that occurred in each of the two experiments is shown in Table 30.

TABLE 30

NUMBER OF DIFFERENT FALSE ALARM TYPES

	S+N	N	%
Experiment I	104	237	43
Experiment II	218	480	45

As can be seen in Table 30, the conventional false alarms occur about twice as frequently as those in the signal plus noise conditions. This is as would be expected since there is no actual or competing target in the noise condition. Of some interest is the fact that the ratio of the two types of false alarms is maintained between both experiments despite the appreciable change in contrast values. Since the false alarms in the signal plus noise conditions are operationally true false alarms, it was decided to combine them with the false alarms under the noise condition for analysis purposes. The confidence ratings of 4 and 3 were simply transferred from the signal plus noise to the noise condition. For inspection purposes, however, the data for subject (1) were evaluated with the false alarms calculated each way (contrast levels were combined). The results are shown in Table 31. As can be seen in this table, sensitivity drops for the combined false alarm data as would be expected since the ratio of hits to false alarms has decreased. The relationship of the Beta values, however, is essentially maintained since the relative proportions of each of these values are not changed (i.e., hits to false alarms).

On the basis of the above decisions, the RSCORE program was applied to the results of each subject with contrast levels and types of false alarms combined. A sample program output is shown in Appendix E. A description of each signal detection output parameter is given in Table 32. A summary of these parameters for each subject is contained in Tables 33 and 34 for Experiments I and II, respectively. The subjects have been arranged in these tables by instructional groups. The first column identifies the subject number. The first row for each subject lists the data identified in the column headings. The second two rows

represent the three Z(k) and Beta values derived from the use of the four confidence ratings as described in Appendix C. The second column indicates whether all confidence categories were used by the subject. Any number less than three indicates that the subject omitted a confidence category and that the calculation of the A (Y-intercept) and B (slope) values in the formula:

$$HR_Z = A+B \cdot FAR_Z$$

was determined by the least squares rather than the maximum likelihood technique. The differences in these approaches are described in Appendix C. This condition occurred in 10 of the 60 subjects in Experiments I and II. These subjects were excluded from any further analyses due to the distortion of their signal detection parameters, as can be seen by inspection of Tables 33 and 34. They are subjects 4, 18, 24, and 28 in Experiment I, and subjects 3, 8, 15, 21, 22, and 24 in Experiment II.

TABLE 31

COMPARISON OF THE EFFECT OF TWO TYPES OF FALSE ALARM DATA

	D(A)		BETA	
FA (noise only)	1.72	.15	.46	3.79
FA (signal plus noise and noise)	1.58	.12	.44	4.17

One interesting statistic in the RSCORE output is "chi-square." This statistic is used as a "goodness-of-fit" measure. If the final value of chi-square is significant for the degree of freedom indicated, it means that the signal detection model does not account for all the variance in the data from the experiment. If chi-square is not statistically significant, we can conclude that the signal detection model provides a satisfactory description of the behavior in the rating scale signal detection experiment. Of the remaining subjects, as shown in the last column of Tables 33 and 34, approximately 50% of the chi-square values in Experiment I were significant, and almost 100% in Experiment II. More than half of these values, however, were artifacts due to a zero frequency in the hit or false alarm rate within a confidence rating. This finding, nevertheless, implies that the signal detection data of this experiment are not as reliable as we would have liked, and implies a departure of some of the data from a normal distribution. The reasons for this problem are presented in the chapter on Discussion. Meaningful data relationships, however, are still available as the following analyses indicate.

TABLE 32

DESCRIPTION OF SIGNAL DETECTION PARAMETERS

"A" The estimate of the numerical value of "A" in the equation

$$HR_Z = A + B \cdot FAR_Z$$

$A = B \cdot$ (Delta m). When the numerical value of R = 1.0, $A = d'$

"B" The estimate of the numerical value of "B" in the equation

$$HR_Z = A + B \cdot FAR_Z$$

"B" is the slope of the above function and represents the ratio of the standard deviation of the noise distribution to the standard deviation of the signal plus noise distribution:

$$B = \frac{\sigma_n}{\sigma_{sn}} \qquad \text{Since } \sigma_n = 1.0 \text{ (assumed)}, \ \sigma_{sn} = 1.0/B$$

"DELTA M" The numerical value of the mean of the signal plus noise distribution expressed in terms of the standard deviation of the noise distribution. It is assumed that $\sigma_n = 1.0$ and $\mu_n = 0.0$

$$\text{DELTA M} = A / B$$

When B = 1.0, DELTA M = A = d'. Delta m = μ_{sn}

"D(A)" The calculated value of d_a, the detectability coefficient to be used in place of d', when the variances of the noise and the signal plus noise distributions are not equal. See Simpson and Fitter, 1973, for a discussion of this index. When B = 1.0, $d_a = d' = \text{delta m} = A$.

$$d_a = \left(\frac{2}{(1+B^2)}\right)^{\frac{1}{2}} \cdot A$$

"Z(K)" These are the numerical values of the various decision criteria used by the subject to divide up the responses into the various response categories. The numbers are on a scale of standard deviation units (z-scores) of the noise distribution. A negative z value indicates a criterion to the left of the noise distribution mean, a positive z value indicates a criterion to the right of the noise distribution mean.

"BETA" These are the numerical values of the various decision criteria expressed in terms of the likelihood ratio at each of the above z values. The values of beta are given by:

TABLE 32 (CONT) DESCRIPTION OF SIGNAL DETECTION PARAMETERS

$$\text{BETA} = \frac{f(x)_{sn}}{f(x)_{n}} \quad \text{where x is the z(k) value given above.}$$

$$f(x)_n = \left(\frac{1}{\sqrt{2\pi}}\right) \text{EXP-}\left[\frac{x^2}{2}\right], \quad f(x)_{sn} = \left(\frac{1}{\sigma_{sn}\sqrt{2\pi}}\right) \text{EXP-}\left[\frac{(x-\mu_{sn})^2}{2\sigma_{sn}^{\ 2}}\right]$$

TABLE 33 SUMMARY OF SIGNAL DETECTION PARAMETERS FOR EXPERIMENT I

INSTRUCTION I

			A	B	DELTA M	D(A)	X^2
1	3		1.2187	.4796	2.5408	1.5539	
1	3	Z(K)	-.5932	.8455	1.6808		
1	3	BETA	.1848	.4926	1.8087		
5	3		1.3242	.3912	3.3350	1.7440	
5	3	Z(K)	-.0674	1.7174	1.9593		
5	3	BETA	.1575	1.3818	2.3358		
12	3		1.3464	.1315	10.2402	1.8879	
12	3	Z(K)	.2255	.5352	1.6860		
12	3	BETA	.0567	.0672	.2300		
15	3		1.2012	.4829	2.4373	1.5297	XX
15	3	Z(K)	-.4637	.7605	1.6500		
15	3	BETA	.1947	.4556	1.7360		
18	2		.4077	.1433	2.8442	.5707	
18	2	Z(K)	1.2017	2.4005			
18	2	BETA	.2870	2.5512			
25	3		1.5224	.1916	7.9459	2.1145	
25	3	Z(K)	.2658	1.9095	2.6065		
25	3	BETA	.0672	.6077	3.3920		
29	3		.9605	.4779	2.0099	1.2255	XX
29	3	Z(K)	-1.9485	1.3190	1.7182		
29	3	BETA	.5331	1.0793	2.0707		
31	3		1.4913	.4013	3.7159	1.9573	
31	3	Z(K)	-1.5072	1.8588	2.0427		
31	3	BETA	.1389	1.7106	2.5801		
33	3		.6082	.4370	1.3919	.7882	
33	3	Z(K)	-1.0938	1.0968	2.4292		
33	3	BETA	.4415	.7903	7.5309		
35	3		1.0818	.2104	5.1413	1.4971	
35	3	Z(K)	-.3766	1.1456	3.0296		
35	3	BETA	.1151	.2852	18.7609		
38	3		.9836	.1370	7.1794	1.3781	
38	3	Z(K)	-.2348	1.5554	1.9764		
38	3	BETA	.0841	.3470	.7523		
40	3		2.6517	.2590	10.2393	3.6302	
40	3	Z(K)	-.4053	1.2224	2.0681		
40	3	BETA	.0063	.0358	.2342		

XX .01 level

TABLE 33 (CONT) SUMMARY OF SIGNAL DETECTION PARAMETERS FOR EXPERIMENT I

INSTRUCTION II

			A	B	DELTA M	D(A)	X^2
2	3		.7102	.4337	1.6372	.9215	
2	3	Z(K)	-.1104	1.5840	1.7081		
2	3	BETA	.3273	1.5201	1.8641		
6	3		.2839	.6049	.4595	.3436	XX
6	3	Z(K)	-2.4889	.5594	1.7924		
6	3	BETA	2.7018	.7061	2.1889		
8	3		1.1912	.5203	2.2396	1.4944	XX
8	3	Z(K)	-.5406	.8789	1.6026		
8	3	BETA	.2035	.5849	2.0385		
11	3		.9102	.1905	4.7795	1.2645	
11	3	Z(K)	.0416	1.5025	3.5984		
11	3	BETA	.1269	.4846	374.7739		
14	3		1.3715	.3917	3.5019	1.8061	X
14	3	Z(K)	-.9319	1.5987	1.8447		
14	3	BETA	.1339	1.0647	1.7393		
17	3		.9937	.3529	2.8159	1.3252	XX
17	3	Z(K)	-.1255	.7263	1.4010		
17	3	BETA	.2075	.3433	.8512		
22	3		1.6362	.3069	5.3322	2.2121	XX
22	3	Z(K)	-.6784	1.3285	2.0836		
22	3	BETA	.0705	.3497	1.6362		
27	3		1.2850	.2839	4.5265	1.7482	XX
27	3	Z(K)	-.9285	.8764	1.8374		
27	3	BETA	.1317	.2442	1.1475		
28	2		-.0696	.0078	-8.8820	-.0984	
28	2	Z(K)	.8647	2.1416			
28	2	BETA	.0113	.0773			
32	3		1.5329	.2768	5.5389	2.0893	XX
32	3	Z(K)	-1.6344	.8753	2.0592		
32	3	BETA	.1467	.1765	1.4505		
34	3		1.3279	.1528	8.0917	1.8564	
34	3	Z(K)	-.1920	1.5599	1.9949		
34	3	BETA	.0620	.2849	.6521		
37	3		.8143	.1231	6.6134	1.1430	XX
37	3	Z(K)	.2023	.8545	1.9351		
37	3	BETA	.0920	.1380	.6784		

XX .01 level
X .05 level

TABLE 33 (CONT) SUMMARY OF SIGNAL DETECTION PARAMETERS FOR EXPERIMENT I

INSTRUCTION III

			A	B	DELTA M	D(A)	X^2
3	3		.2807	.60[illegible]7	.4665	.3402	XX
3	3	Z(K)	-2.2083	.3597	1.5938		
3	3	BETA	1.8873	.6406	1.7026		
4	1		1.9567	1.0000	1.9567	1.9567	
4	1	Z(K)	1.5264				
4	1	BETA	2.9224				
7	3		1.6714	.1131	14.7837	2.3488	X
7	3	Z(K)	.5154	1.3506	2.5743		
7	3	BETA	.0351	.0888	1.1934		
10	3		1.1145	.0898	12.4053	1.5699	
10	3	Z(K)	.4688	1.2717	2.0356		
10	3	BETA	.0564	.1223	.4522		
13	3		1.5716	.1557	10.0917	2.1961	
13	3	Z(K)	-.2599	1.9113	2.4600		
13	3	BETA	.0439	.4298	1.5839		
19	3		1.2101	.2144	5.6430	1.6733	XX
19	3	Z(K)	-.0194	1.0930	1.8714		
19	3	BETA	.1026	.2421	.8908		
20	3		1.3515	.1574	8.5867	1.8881	
20	3	Z(K)	.0127	1.5737	2.5340		
20	3	BETA	.0633	.2952	2.4788		
23	3		1.0942	.0419	26.1319	1.5460	
23	3	Z(K)	.3468	.8100	2.1700		
23	3	BETA	.0248	.0231	.2666		
24	2		1.1934	.0090	131.9989	1.6877	
24	2	Z(K)	1.3003	2.4064			
24	2	BETA	.0105	.0823			
26	3		1.4161	.2177	6.5058	1.9568	XX
26	3	Z(K)	.0143	.5596	2.4006		
26	3	BETA	.0802	.1102	2.6047		
42	3		1.7297	.2115	8.1786	2.3932	
42	3	Z(K)	-.0554	.9553	2.5712		
42	3	BETA	.0465	.1039	2.8540		
43	3		1.8728	.2612	7.1710	2.5626	
4[illegible]	3	Z(K)	.4966	1.2952	1.9583		
4[illegible]	3	BETA	.0647	.1861	.7166		

XX .01 level
X .05 level

TABLE 34 SUMMARY OF SIGNAL DETECTION PARAMETERS FOR EXPERIMENT II

INSTRUCTION I

			A	B	DELTA M	D(A)	X2
1	3		1.1218	.2089	5.3703	1.5530	XX
1	3	Z(K)	-2.2093	-.2110	1.7202		
1	3	BETA	.6833	.1082	.6859		
4	3		.6844	.3788	1.8059	.9052	XX
4	3	Z(X)	-1.9054	.0334	1.5122		
4	3	BETA	.8658	.3024	1.1810		
8	2		.9324	.1120	8.3275	1.3104	
8	2	Z(K)	.4440	2.1725			
8	2	BETA	.0837	.9351			
9	3		.8777	.4148	2.1163	1.1466	XX
9	3	Z(K)	-1.8496	-.2874	1.6790		
9	3	BETA	.5931	.2630	1.6704		
13	3		.3662	.5385	.6799	.4559	XX
13	3	Z(K)	-1.8776	.8963	1.7927		
13	3	EETA	1.2156	.8006	2.2445		
14	3		.8048	.3739	2.1523	1.0660	XX
14	3	Z(K)	-1.1457	.6420	1.6416		
14	3	BETA	.3370	.3918	1.4126		
17	3		.7031	.5772	1.2180	.8611	X
17	3	Z(K)	-2.4576	.3745	1.2802		
17	3	BETA	1.2457	.5499	1.2766		
23	3		1.2215	.1427	8.5927	1.7102	XX
23	3	Z(K)	-.7741	-.1241	1.9554		
23	3	BETA	.0793	.0667	.6189		

XX .01 level
X .05 level

TABLE 34 (CONT) SUMMARY OF SIGNAL DETECTION PARAMETERS FOR EXPERIMENT II

INSTRUCTION II

			A	B	DELTA M	D(A)	X2
2	3		1.4428	.2735	5.2764	1.9682	XX
2	3	Z(K)	-1.8153	.7771	2.0261		
2	3	BETA	.2167	.1735	1.4347		
6	3		.8660	.2629	3.2542	1.1844	XX
6	3	Z(K)	-.0911	.8541	1.7985		
6	3	BETA	.1777	.3082	1.2262		
7	3		.5782	.4589	1.2599	.7431	XX
7	3	Z(K)	-.7243	.7584	1.5698		
7	3	BETA	.3941	.5958	1.5576		
12	3		.7720	.5415	1.4256	.9600	XX
12	3	Z(K)	-.4209	.5611	1.1358		
12	3	BETA	.3589	.5581	1.0195		
15	2		91.7706	33.4077	2.3844	3.3709	
15	2	Z(K)	2.3844	2.3344			
15	2	BETA	660.5334	628.2114			
18	3		.5369	.5159	1.0408	.6748	XX
18	3	Z(K)	-1.6534	.2587	1.4593		
18	3	BETA	.7703	.4917	1.4627		
20	3		-.0451	.4522	-.0996	-.0581	XX
20	3	Z(K)	-2.8394	-.7170	1.2852		
20	3	BETA	11.8212	.5624	.8489		
22	2		.9165	.0033	278.1123	1.2962	
22	2	Z(K)	-.5545	2.4799			
22	2	BETA	.0025	.0472			

XX .01 level
X .05 level

TABLE 34 (CONT) SUMMARY OF SIGNAL DETECTION PARAMETERS FOR EXPERIMENT II

INSTRUCTION III

			A	B	DELTA M	D(A)	X2
3	2		5.6750	2.8397	2.0048	2.6733	
3	2	Z(K)	1.8417	2.1351			
3	2	BETA	13.8737	25.8396			
5	3		1.2569	.7741	1.6236	1.4056	
5	3	Z(K)	-1.1409	1.1406	2.1480		
5	3	BETA	.1503	1.3839	7.1607		
10	3		1.0137	.4260	2.3251	1.3142	
10	3	Z(K)	-1.4689	.5251	2.4269		
10	3	BETA	.3265	.3878	8.2739		
11	3		.8595	.4037	2.1290	1.1271	XX
11	3	Z(K)	-2.3746	1.1921	1.6764		
11	3	BETA	1.2962	.7649	1.6184		
16	3		.8683	.7034	1.2345	1.0044	X
16	3	Z(K)	-1.9971	1.2044	1.7259		
16	3	BETA	.3902	1.4524	2.9382		
19	3		1.3164	.3684	3.5732	1.7469	XX
19	3	Z(K)	.3893	1.2542	2.0062		
19	3	BETA	.1997	.5616	2.3231		
21	2		40.7249	16.7266	2.4347	3.4371	
21	2	Z(K)	2.3844	2.3944			
21	2	BETA	201.4807	234.2402			
24	2		1.4399	.2634	5.4656	1.9691	
24	2	Z(K)	.7122	2.4122			
24	2	BETA	.1550	3.4975			

XX .01 level
X .05 level

The individual signal detection parameters of each subject determined by the above RSCORE analyses served as input to a two-way analysis of variance, with the three levels of instruction and two levels of contrast as the independent variables. The dependent variables were D(A), Beta, A(Y-intercept), B (slope), Delta M, and Z(k). The design is schematically illustrated in Table 35.

TABLE 35

TWO-WAY ANALYSIS OF VARIANCE DESIGN
FOR SIGNAL DETECTION PARAMETERS

Experiment	Instruction	N
I (high contrast)	I	11
	II	11
	III	10
II (low contrast)	I	7
	II	6
	III	5
		N = 50

The number of subjects remaining in each experimental condition is shown in the last column of Table 35. Prior to this analysis, the three Z(k) and Beta values of each individual were averaged to simplify the analyses. The arithmetic mean of the Z(k) values was calculated, while the log transformation of the geometric mean of the Beta values was calculated. The latter approach was taken since the unbiased criterion point of Beta is 1, with an equal probability of values on either side of one. The resulting averages are contained in Appendix F. This appendix has the same format as the signal detection parameters summarized in Tables 33 and 34, with the exception that the three Z(k) and Beta values are averaged. This output served as the input to the analysis of variance. The significant relationships found in these analyses are summarized in Table 36.

TABLE 36

SIGNIFICANT RELATIONSHIPS BETWEEN SIGNAL DETECTION PARAMETERS AND INSTRUCTION AND CONTRAST VARIABLES

Dependent Variable	Independent Variable
A (Y-intercept)	Contrast ***
B (slope)	Contrast *** Contrast x Instruction **
Delta M	Contrast *** Instruction ***
D (A)	Contrast ***
Z(K)	Contrast *** Instruction *

*** .01 level
** .05 level
* .0556 level

One unexpected finding as a result of these analyses was the change in the magnitude and pattern of data relationships between the Beta and Z(K) values as shown in Figures 16 and 17 (which were based on the data shown in Tables 37 and 39, respectively), and the lack of any main effects for Beta as opposed to the Z(K) values as can be seen in Tables 38 and 40. It was anticipated that the results would be nearly identical for both parameters, since they are both measures of response bias. The Z(K) values, as described in Table 32, are on a scale of standard deviation units (Z-scores) of the noise distribution. The Beta values are a monotonic transformation of these values, expressed in terms of the likelihood ratio, at each of the above Z(K) values. The Beta values, however, may have been distorted by the lack of equal variance between the signal and noise distributions. It is also possible that distortion was introduced by the calculation of the geometric mean and log transformation. Since Z(K) and Beta have the same meaning theoretically (before averaging), it was decided to use Z(K) as the measure for bias in the subsequent analyses.

In view of the apparent distortion in the Beta values and the fact that the signal detection model is essentially a model for the results of one individual, other possible distortion effects were considered. Since Delta M = A/B, then A = Delta M · B. By application of the latter equation, A = 1.83 for high contrast, and 1.09 for low contrast. The actual values for A, however, from Table 45 are 1.24 and .84, respectively. Apparently, some distortion has also been introduced

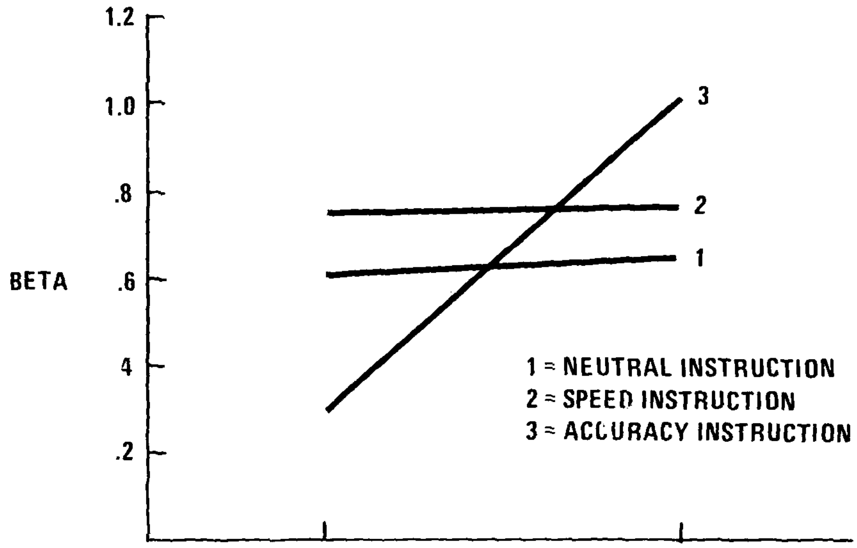

Figure 16. Relationship of beta, contrast, and instruction.

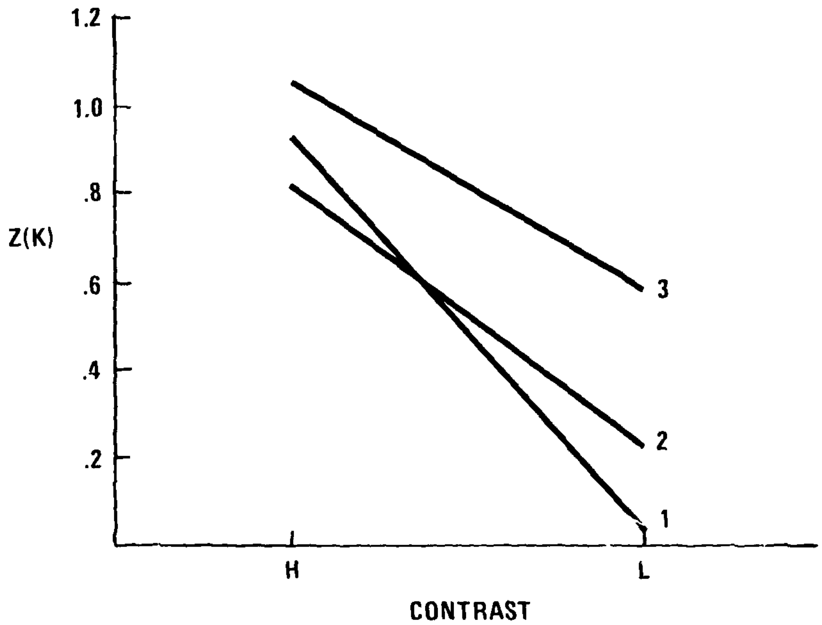

Figure 17. Relationship of Z(K), contrast, and instruction.

TABLE 37

SUMMARY OF BETA VALUES FOR
CONTRAST AND INSTRUCTION

INSTRUCTION	CONTRAST HIGH	CONTRAST LOW	ROW MEAN
NEUTRAL	.633	.665	.645
SPEED	.774	.782	.777
ACCURACY	.331	1.027	.563
COL MEAN	.587	.805	

TABLE 38

SUMMARY OF ANALYSIS OF VARIANCE FOR BETA,
CONTRAST AND INSTRUCTION

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	.14	2	.07	.26
B. CONTRAST	.69	1	.69	2.62
A X B	1.15	2	.58	2.20
WITHIN CELLS	11.53	44	.26	
TOTAL	13.51	49		

TABLE 39

SUMMARY OF MEAN Z(K) VALUES FOR
CONTRAST AND INSTRUCTION

	CONTRAST		
INSTRUCTION	HIGH	LOW	ROW MEAN
NEUTRAL	.927	.032	.579
SPEED	.824	.235	.616
ACCURACY	1.089	.580	.919
COL MEAN	943	.252	

TABLE 40

SUMMARY OF ANALYSIS OF VARIANCE FOR Z(K),
CONTRAST AND INSTRUCTION

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	1.12	2	.56	3.14*
B. CONTRAST	5.03	1	5.03	28.15**
A X B	.32	2	.16	.89
WITHIN CELLS	7.83	44	.18	
TOTAL	14.32	49		

**p = .01
*p = .0556

here due to averaging, although the same data relationship is maintained between "A" for high and low contrast. In addition, ROC curves plotted with either value have a consistent pattern as discussed later for Figures 22 to 25. The ROC curves based on the average A values, however, were considered more representative due to the fact that the Delta M values may be unreliable since the noise and signal plus noise distribution do not have equal variances, as discussed later.

Table 39 shows the relationship of the mean Z(K) values to the independent variables of instruction and contrast. The results of the analysis of variance are shown in Table 40. As can be seen, Z(K) is significant for contrast and almost significant for instruction (P = .0556). Instructional effects were expected to be the prime determinant of response bias. While not significant, the P value indicates a trend in this direction. The data of Table 39 are plotted in Figure 17. In this figure, it can be seen that the accuracy instruction group had the higher Z(K) values. The values for the speed and neutral instructional groups change as a function of contrast. This interaction, however, is not significant. The relative position of these values on a ROC curve is discussed later, with pertinent data shown in Table 49. The significant effects for contrast are not only contrary to expectations, but also stronger than the effect of instruction. In this respect, it is apparent that the higher contrast level created greater confidence and led to a higher response criterion in the subjects.

Table 41 presents the mean values obtained for B (slope) with the instruction and contrast values. Table 42 presents the results of the analysis of variance. As can be seen in Table 41, the higher contrast has a shallower slope than the lower contrast value, .291 and .435, respectively. This is a typical finding of signal detection experiments, since the variability of the signal distribution increases as the signal strength increases. As discussed in Appendix C, the standard deviation of the signal plus noise distribution can be determined by

$$C_{sn} = \frac{1.0}{B(\text{slope})}$$

Since B (slope) is not 1, the variances of the noise and signal distributions are not equal (since the variance of the noise distribution is assumed to be one). This justifies the original decision to calculate D(A) rather than d', since the former is not influenced by unequal variances. B (slope) is also related to sensitivity and hence would be independent of the instruction variable. This is the case since B (slope), like D(A), has no significant relation to instructions. In addition, the mean values for slope for each instruction level are nearly equivalent (Table 41). This implies that this value (subject to validation) can be used in future experiments to determine D(A) and Beta values, without the need to resort to confidence ratings, as explained in Appendix C. If B had equalled one, it would be possible to determine the

TABLE 41

SUMMARY OF B(SLOPE) VALUES FOR
CONTRAST AND INSTRUCTION

INSTRUCTION	CONTRAST HIGH	LOW	ROW MEAN
NEUTRAL	.327	.377	.346
SPEED	.352	.417	.375
ACCURACY	.206	.591	.335
COL MEAN	.298	.450	

TABLE 42

SUMMARY OF ANALYSIS OF VARIANCE FOR B(SLOPE),
CONTRAST AND INSTRUCTION

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	.02	2	.01	.37
B. CONTRAST	.32	1	.32	13.18**
A X B	.27	2	.14	5.67**
WITHIN CELLS	1.05	44	.02	
TOTAL	1.66	49		

**p = .01

d' and Beta values from tables available for this purpose. Figure 18 shows the significant interaction between instruction and constrast as indicated in Table 42. This interaction for the accuracy instruction is probably a function of the significant change in the relationship of its hits to false alarms at high and low contrast as shown in Figures 9 and 11.

Table 43 presents the mean values obtained for D(A) with the instruction and contrast values. Table 44 presents the results of the analysis of variance. As anticipated, D(A) is significant for contrast. Sensitivity increases when the number of hits increases due to higher contrast without a corresponding increase in false alarms. Figure 19 illustrates the relationships obtained for D(A) relative to each instructional level. As can be seen in Figure 19, the accuracy instruction is the most sensitive with the speed instruction the least sensitive. The relationships, although not significant, are similar to those obtained for frequency of hits as shown in Figure 9.

The next two parameters A (y-intercept) and Delta M are interrelated and determined by B, as follows:

$$\text{Delta M} = A/B$$

$$A = B \cdot \text{Delta M}$$

When B = 1.0, Delta M = A = d'. Table 45 presents the mean values for A with the contrast and instruction variables. Table 46 presents the results of the analysis of variance. The latter table shows that only contrast is significant. This result is as expected since A is related to d' when B = 1.0. The parameter A is plotted in Figure 20. The data relationships are similar to those for D(A) as plotted in Figure 19. Table 47 presents the mean values obtained for Delta M with the instruction and contrast variables. Table 48 presents the results of the analysis of variance. This table shows that only contrast is significant. This result is consistent with the above due to the identity relationship of Delta M, A, and d', when B = 1. Delta M, however, can be considered a less optimal measure since unlike D(A), it is not immune to the effects of unequal variances between the signal and noise distributions. Its data are plotted in Figure 21.

Thus, in the preceding analyses, it is apparent that D(A) as a measure of sensitivity was influenced by contrast as expected. It was also seen that D(A) was systematically influenced by instruction although the results were not significant. Although not significant, Z(K) was influenced by instructions as expected. It was also strongly influenced by contrast. The latter result can be explained since one of the contrast levels was significantly easier than the other, thereby influencing the subject's response criterion. The other signal detection paramet 'rs are also generally consistent with the above, given that the average slope was less than one, which is the generally assumed

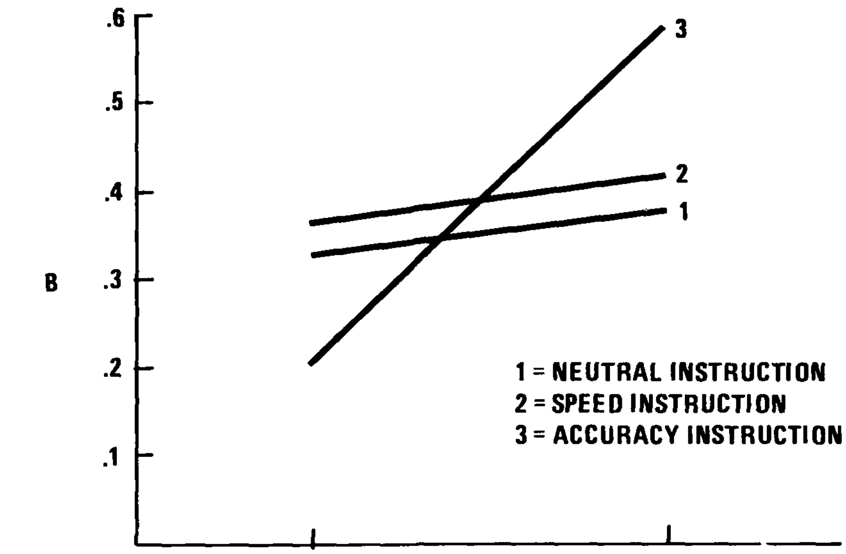

Figure 18. Relationship of B(slope), contrast, and instruction.

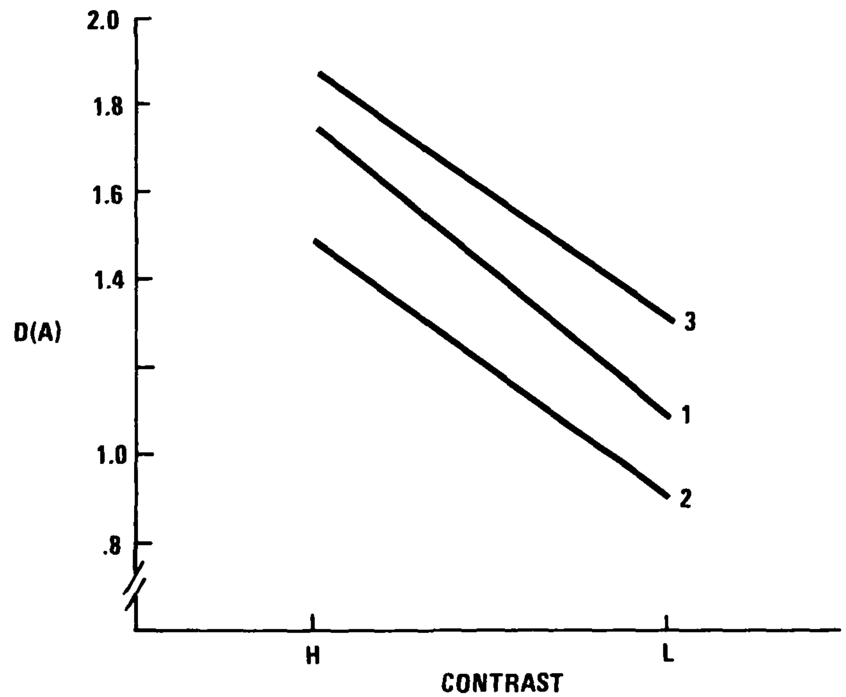

Figure 19. Relationship between D(A), contrast, and instruction.

TABLE 43

SUMMARY OF D(A) VALUES FOR
CONTRAST AND INSTRUCTION

INSTRUCTION	CONTRAST HIGH	CONTRAST LOW	ROW MEAN
NEUTRAL	1.755	1.099	1.500
SPEED	1.473	.912	1.275
ACCURACY	1.847	1.320	1.671
COL MEAN	1.687	1.098	

TABLE 44

SUMMARY OF ANALYSIS OF VARIANCE FOR D(A),
CONTRAST AND INSTRUCTION

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	1.17	2	.59	1.66
B. CONTRAST	3.84	1	3.84	10.89**
A X B	.03	2	.02	.05
WITHIN CELLS	15.53	44	.35	
TOTAL	20.59	49		

**p = .01

TABLE 45

SUMMARY OF A(Y-INTERCEPT) VALUES FOR
CONTRAST AND INSTRUCTION

	CONTRAST			
INSTRUCTION	HIGH	LOW	*	ROW MEAN
NEUTRAL	1.311	.826	*	1.122
SPEED	1.096	.692	*	.953
ACCURACY	1.331	1.063	*	1.242
COL MEAN	1.243	.847	*	

TABLE 46

SUMMARY OF ANALYSIS OF VARIANCE FOR A(Y-INTERCEPT),
CONTRAST AND INSTRUCTION

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	.70	2	.35	1.93
B. CONTRAST	1.69	1	1.69	9.33**
A X B	.09	2	.05	.25
WITHIN CELLS	7.99	44	.18	
TOTAL	10.48	49		

**p = .01

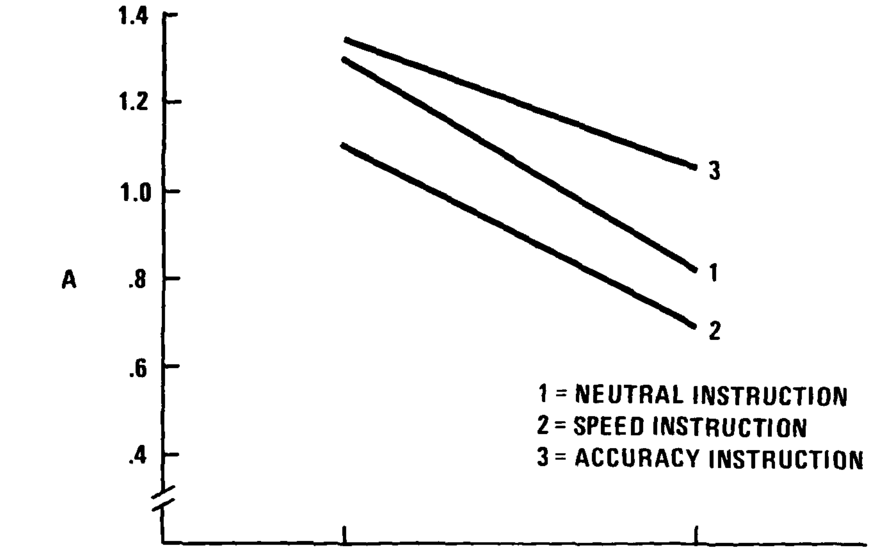

Figure 20. Relationship of A (Y-intercept), contrast, and instruction.

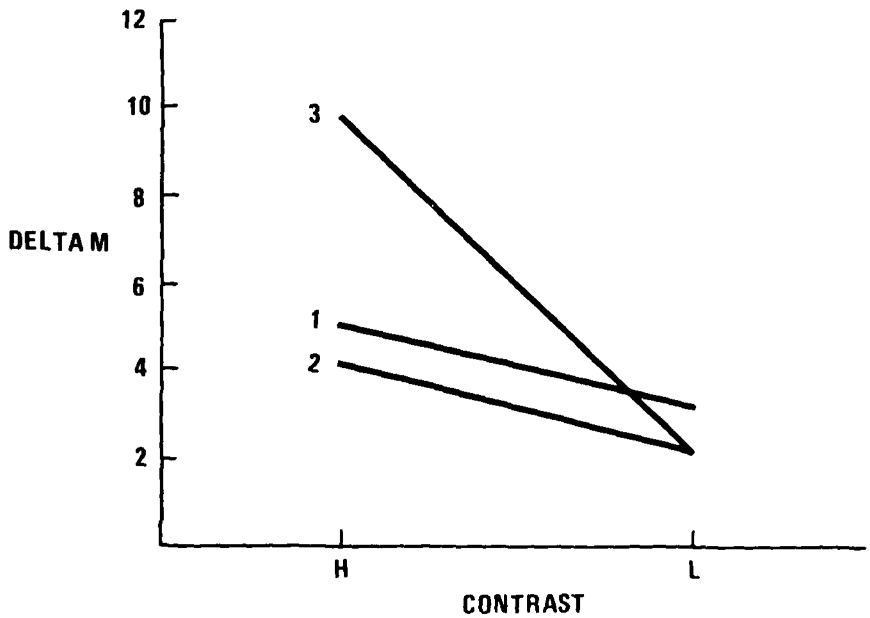

Figure 21. Relationship of Delta M, contrast, and instruction.

TABLE 47

SUMMARY OF DELTA M VALUES FOR
CONTRAST AND INSTRUCTION

CONTRAST

INSTRUCTION	HIGH	LOW	ROW MEAN
NEUTRAL	5.12	3.13	4.34
SPEED	4.20	2.03	3.43
ACCURACY	10.00	2.18	7.39
COL MEAN	6.33	2.50	

TABLE 48

SUMMARY OF ANALYSIS OF VARIANCE FOR DELTA M,
CONTRAST AND INSTRUCTION

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	69.22	2	34.61	2.32
B. CONTRAST	181.14	1	181.14	12.13**
A X B	83.41	2	41.70	2.79
WITHIN CELLS	656.86	44	14.93	
TOTAL	990.63	49		

**p = .01

value in most experiments. It would appear, as a result, that the signal detection model, despite the limitations indicated above, provided a reasonable representation of the experimental results.

The above data provide the necessary input to plot the group ROC curves, in order to schematically represent the results of the primary signal detection parameters (D(A) and Beta). Since D(A) was not significant for instruction but significant for contrast, it will be necessary to plot curves only for each contrast. The formula for the group ROC curve is the same as that for an individual:

$$HR_Z = A + B \cdot FAR_Z$$

The curves are simply plotted by substituting the values of A and B for each contrast level into the above formula, and solving for HR_Z in any given FAR_Z value. The curves, however, were plotted for the average A values and the adjusted A values, as discussed previously, based on the following relationship: A = Delta M · B. The ROC curves were also plotted for cumulative probabilities, by conversion of the HR_Z and FAR_Z values. Figures 22 and 23 represent the ROC curves based on Z transformation of the HR-FAR values for the mean and adjusted A values, respectively. Figures 24 and 25 represent the ROC curves based on cumulative probabilities for the mean and adjusted A values, respectively. It can be seen by comparing Figure 22 to 23 and 24 to 25, that the sensitivity of the curves for the adjusted values is somewhat higher than those for the average values. The average A value, however, is considered more reliable, since Delta M = d', when B = 1. As noted earlier, B is less than 1, and as a result each subject's Delta M value is less than optimal even before averaging.

By inspection of these figures, two results are obvious. The higher contrast is more sensitive than the lower contrast, and the lines are oblique to the diagonal since the variances of the signal plus noise and noise distribution are not equal. The curves based on cumulative probability are also skewed to the right for the same reason.

It is difficult to locate a specific location for each instructional set on the curves themselves. The approximate locations can be determined, however, by solving for FAR_Z when $HR_Z = 1$ for each instructional set. These values are calculated separately for each instructional set at high and low contrast. The resulting values are shown in Table 49. It is apparent that the accuracy instruction would fall to left portion of the ROC curve, while the speed group would fall to right portion of the ROC curve, with the neutral group near the middle. The results are somewhat similar for both contrast conditions, and are consistent with expectations.

Although D(A) was not significant for instruction, a separate ROC curve is also plotted for each instructional level for high contrast. It is apparent in Figure 26 that sensitivity increases with instruction

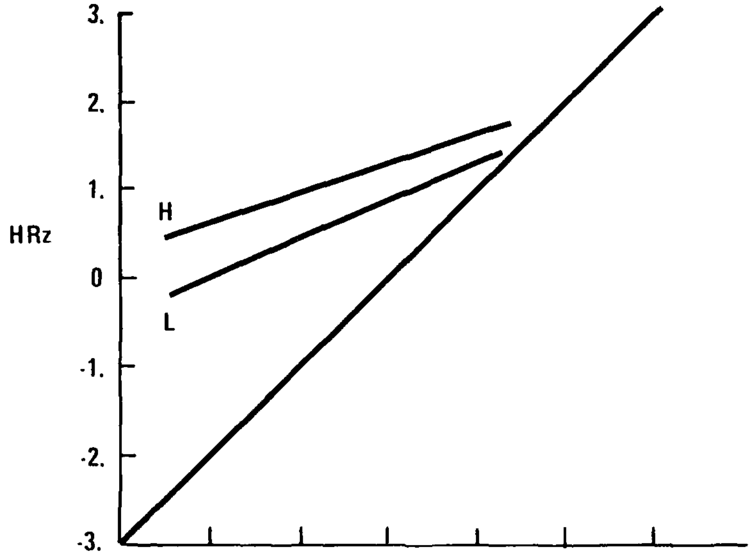

Figure 22. Group ROC curve (Z transformation), on average signal detection parameters.

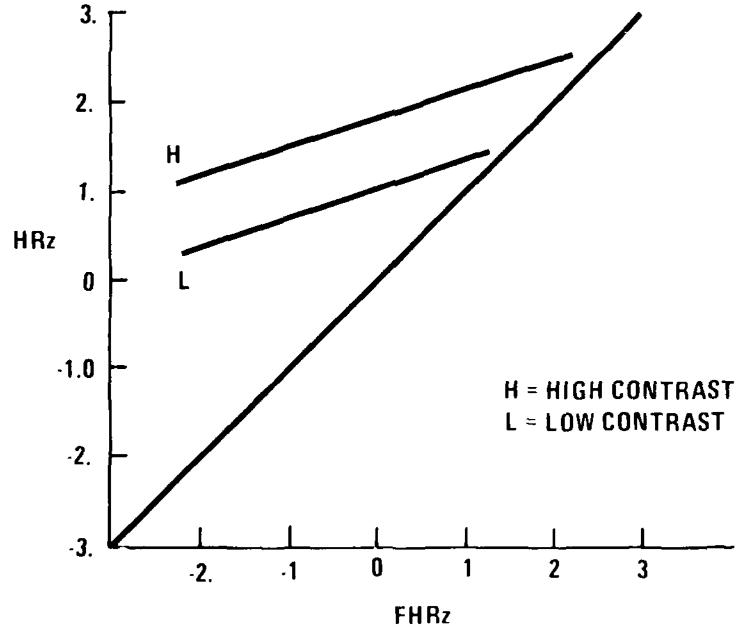

Figure 23. Group ROC curve (Z transformation), on adjusted signal detection parameters.

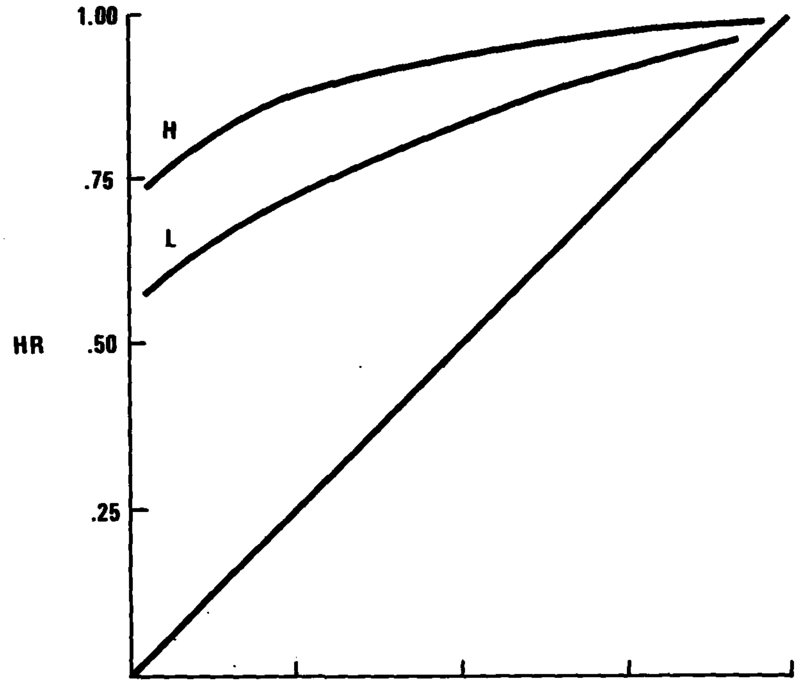

Figure24 . Group ROC Curve (Cumulative Probability) on Average Signal Detection Parameters

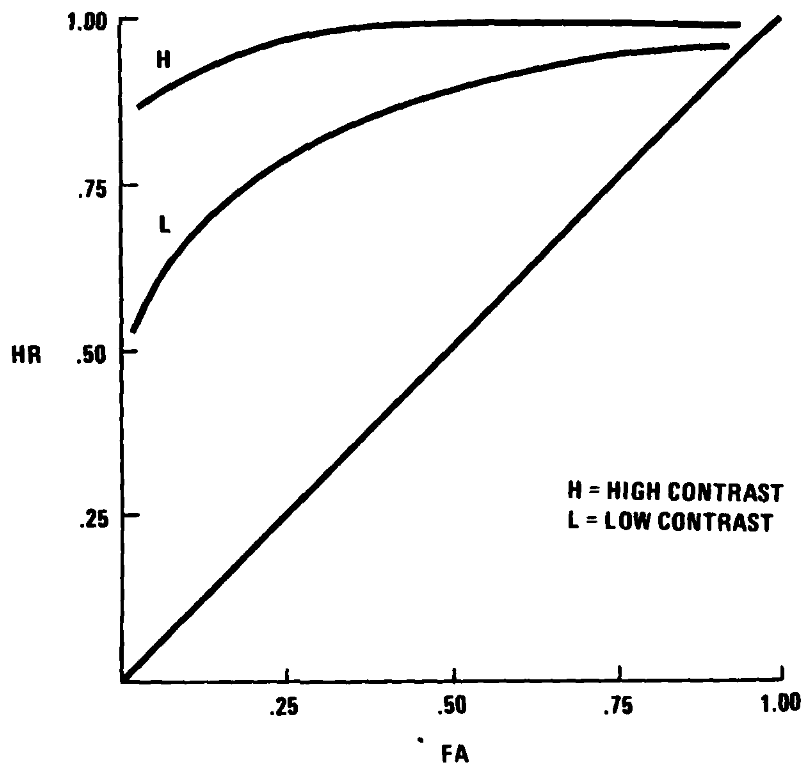

Figure 25. Group ROC Curve (Cumulative Probability) on Adjusted Signal Detection Parameters

in the order shown. These results are similar to Figure 19, plotted for D(A) and instruction at each contrast level, which in turn is similar to Figure 9 plotted for the frequency of hits negative to instruction and contrast.

TABLE 49

FAR_Z VALUES FOR HIGH AND LOW CONTRAST WHEN $HR_Z = 1$

Instructional Set	FAR_Z High Contrast	FAR_Z Low Contrast
I	-.95	+.46
II	-.29	+.73
III	-1.61	-.11

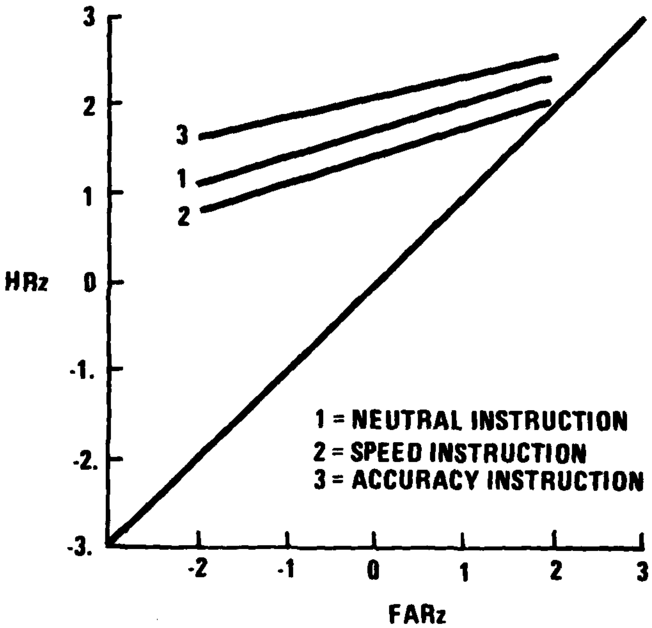

Figure 26. ROC curves (Z transformation) by instructional group

Analyses of Covariance

The next step undertaken in the analysis of the results was to determine whether there was any relationship between the primary signal detection parameters of D(A) and Z(K) with reaction time and the number of hits. A basic consideration before attempting such an analysis was to determine whether the relationship between these variables was linear or curvilinear. All of the data were first converted to standard (Z) scores. This was done to avoid the potentially spurious results that could occur due to the difference in mean values resulting from the pooled data of the independent variables to be used in the regression analyses. In this latter analysis, the following variables were independently related to the log reaction time and hit data by a simple stepwise (forced) regression in the order shown:

$$D(A) \text{ and } D(A)^2$$

$$Z(K) \text{ and } Z(K)^2$$

The data from this step-wise regression were then tested to determine whether there was a significant increase in variance due to the multiple correlation of $D(A)^2$ or $Z(K)^2$ when added to their counterpart, which would indicate a curvilinear relationship. In this test, the resulting multiple R would also have to be significant.

The only variable which met both of the above criteria was the multiple correlation of ZK and $Z(K)^2$ with log reaction time. The increase in the sum of squares was significant at the .01 level ($F\ (2,47) = 7.02$, $p < .01$). The multiple correlation of ZK and $Z(K)^2$ with reaction time (.36) was significant at the .05 level ($F\ (2,47) = 3.62$, $p < .05$). The simple correlation of Z(K) with reaction time, however, was only -.06. The intercorrelation of Z(K) and $Z(K)^2$ was .86. Inspection of a plot between Z(K) and reaction time indicated an even linear scatter of points, without a meaningful functional relationship consistent with the -.06 correlation. In view of the latter, the significant curvilinear finding was attributed to an unstable multiple regression possibly due to the high intercorrelation between Z(K) and $Z(K)^2$. This view was supported by the fact that Z(K) and $Z(K)^2$ also had beta weights with reverse signs. As a result, $Z(K)^2$ was not used as a covariate in the analysis of covariance.

A two-way analysis of covariance model was not available which would separately show the correlation of the covariates D(A) and Z(K) with the dependent variables of reaction time and number of hits. As a result, these values were calculated separately prior to the conduct of the analysis of covariance. A simple step-wise regression, employing the standard scores, was conducted using DA and ZK relative to reaction time and hits treated separately. This analysis, like the one conducted for the test of curvilinearity, was based on the pooled data of all of the experimental conditions. This was done to assure compatibility of

the values with those obtained in the two-way analysis of covariance. The simple correlations and multiple correlations as a result of the analysis are shown in Tables 50 and 51, respectively.

TABLE 50

SIMPLE CORRELATIONS OF D(A) AND Z(K) WITH REACTION TIME AND NUMBER OF HITS

	RT	HITS
DA		
DA	-.19	.59*
ZA	-.06	.22

*p = .01

TABLE 51

MULTIPLE CORRELATION OF D(A) AND Z(K) WITH REACTION TIME AND NUMBER OF HITS

RT	HITS
.20	.62*

*p = .01

As can be seen in these tables, only the simple R (.59) of DA and hits is significant, and the multiple R (.62) of DA and ZK is significant. In the latter case, inspection of the regression analyses indicated that Z(K) contributed only 3% of additional variance to the multiple R, which is consistent with the low value of its simple R (.22). In addition, the intercorrelation of D(A) and Z(K) is .61. In contrast to the correlation of these variables with hits, little if any meaningful correlation existed between them and reaction time.

The two-way analysis of covariance was run with both the D(A) and Z(K) values used simultaneously as the covariates. Inspection of the Z(K) data indicated that it could remove some additional variance, though small, and would not introduce any anomalies in the analyses since its beta weights were proportional to those of the D(A) values. The dependent variables in this analysis were reaction time and the number of hits. The number of subjects was 50. Since the original

two-way analyses of variance between these dependent measures and the independent variables of contrast and instruction involved 60 subjects, these analyses were conducted again with the reduced number of subjects. This was necessary to assure that any change in the results was due to the influence of the covariates rather than the change in the number of subjects. The new mean values for hits obtained with each of the experimental conditions is shown in Table 52, with the summary of the analysis of variance shown in Table 53. The original values obtained for the 60 subjects can be found in Tables 12 and 13. Comparison of the mean values in Table 52 and Table 12 shows negligible change in the cell, as well as in the column and row means. Despite the near equivalence of the results, the significant main effects for instruction were lost in the analysis with the reduced number of subjects, while the main effects for contrast remained significant, as can be seen in Table 53.

The new mean values for reaction time obtained with each of the experimental conditions is shown in Table 54, with the summary of the analysis of variance shown in Table 55. The original values obtained for the 60 subjects are shown in Tables 10 and 11. The mean values between both analyses were also similar, with no change in the main effects, since both contrast and instruction were significant.

The adjusted mean hit values of the analysis of covariance are shown in Table 56, with a summary of the analyses of covariance found in Table 57. It can be seen in Table 56 that any differences in cell, column, or row means have been removed, when compared to the unadjusted values shown in Table 52. In addition, the main effects for contrast and instruction have also been lost as can be seen in Table 57. Even though the main effect for instruction had been lost when the number of subjects had been reduced to 50, before adjustment by covariance, inspection of the row means of Table 56 shows that the mean values for instruction are similar as opposed to the differences found in Table 52. Moreover, all of the means in Table 56 are similar to each other, and fall in the range of 39-40. In effect, the differences in the number of hits as a function of instruction and contrast no longer exist. The Beta weights for D(A) and Z(K) in this analysis were 12.40 and 5.57, respectively, indicating that Z(K) had a small role.

The above results in the case of contrast are not clear cut, since the covariate D(A) is also influenced by the independent variable of contrast as can be seen by the significant F ratio in Table 44. If D(A) had not been related to contrast, one could assume that the same results might have still occurred for the following reason. The variance between D(A) and the dependent variable (hits) was .38, which exceeded by two-fold the variance between D(A) and contrast (.18). In addition, the variance between D(A) and hits also accounted for the adjustment of hits between instructional levels, where no relationship between the covariate and the independent variable was found.

TABLE 52

MEAN FREQUENCIES OF HITS (N = 50)

	CONTRAST		
INSTRUCTION	HIGH	LOW	LOW MEAN
NEUTRAL	42.82	32.57	38.83
SPEED	39.82	28.83	35.94
ACCURACY	47.60	36.60	43.93
COL MEAN	43.28	32.44	

TABLE 53

ANALYSIS OF VARIANCE TABLE FOR FREQUENCIES OF HITS (N = 50)

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	460.96	2	230.48	2.61
B. CONTRAST	1312.80	1	1312.80	14.87**
A x B	1.41	2	.70	.01
WITHIN CELLS	3883.42	44	88.26	
TOTAL	5658.59	49		

**p = .01

TABLE 54

MEAN REACTION TIMES OF HITS (N = 50)

	CONTRAST		
INSTRUCTION	HIGH	LOW	LOW MEAN
NEUTRAL	8.75	10.84	9.51
SPEED	6.31	6.98	6.53
ACCURACY	8.18	11.83	9.25
COL MEAN	7.66	9.59	

TABLE 55

ANALYSIS OF VARIANCE TABLE FOR REACTION TIME
OF HITS (N = 50)

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	.29	2	.14	13.49**
B. CONTRAST	.11	1	.11	10.46**
A x B	.03	2	.01	1.20
WITHIN CELLS	.47	44	.01	
TOTAL	.90	49		

**p = .01

TABLE 56

MEAN FREQUENCIES OF ADJUSTED HITS

CONTRAST

INSTRUCTION	HIGH	LOW		ROW MEAN
NEUTRAL	38.04	40.92	*	39.16
SPEED	39.11	38.38	*	38.85
ACCURACY	40.78	39.16	*	40.23
COL MEAN	40.43	39.85	*	

TABLE 57

ANALYSIS FOR COVARIANCE TABLE FOR ADJUSTED
FREQUENCIES OF HITS

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	10.09	2	5.04	.38
B. CONTRAST	.21	1	.21	.01
A X B	42.94	2	21.46	1.62
D(A)	1898.80	1	1898.80	143.62**
Z(K)	194.17	1	194.16	14.68**
DA x ZK	3328.15	2	1664.07	125.87**
ERROR	555.27	42	13.22	

BETA WEIGHTS
D(A) 12.40
Z(K) 5.57

**p = .01

The adjusted mean values for reaction time from the analysis of covariance are shown in Table 58, with a summary of the analysis of covariance found in Table 59. The unadjusted values are shown in Tables 54 and 55. As can be seen by the inspection of the values in Tables 54 and 58, little change has occurred between the adjusted and unadjusted reaction time values. While the main effect for instruction is still significant, the main effect for contrast, however, has been lost which implies an impact as a result of the covariates. The Beta values of DA and ZK, however, were small and insignificant (-.04 and .00, respectively) as was their multiple correlation with reaction time (.20). The loss of significance for contrast, as a result, can be considered an artifact. This view is supported by the negligible changes in the adjusted mean reaction time values.

It is apparent from the above that D(A), as the strongest covariate, can adjust for the number of hits but has little or no value with respect to reaction time. As discussed later, this can be attributed to the fact that D(A) is primarily a function of the number of hits, and consequently its correlation with hits is both intrinsic and high. In addition, it was determined that there is a low (and linear) correlation between hits and reaction time, as well as between false alarms and reaction time as shown in Table 60. The lack of a meaningful correlation between hits and reaction time would account for the lack of any meaningful relationship between D(A) and reaction time. These relationships are discussed more fully in the following chapter.

TABLE 60

CORRELATION OF REACTION TIME WITH HITS AND FALSE ALARMS

	Exper 1	Exper 2	Combined Experiment
HITS	-.31*	.03	-.19
FA	-.15	-.14	.00

*p = .05

CHAPTER VI. DISCUSSION

This chapter will discuss the results of the conventional analysis of hit and reaction time data, the results of the signal detection analysis, and finally the use of signal detection data in an analysis of covariance to adjust for the effects of instructional set.

TABLE 58

MEAN REACTION TIME OF ADJUSTED HITS

	CONTRAST			
INSTRUCTION	HIGH	LOW		ROW MEAN
NEUTRAL	9.04	10.35	*	9.53
SPEED	6.28	6.55	*	6.37
ACCURACY	8.53	11.64	*	9.46
COL MEAN	7.83	9.18	*	

TABLE 59

ANALYSIS OF COVARIANCE TABLE FOR ADJUSTED REACTION TIMES

SOURCE OF VARIATION	SUM SQ	D F	MEAN SQ	F VALUE
A. INSTRUCTION	.327	2	.163	15.72**
B. CONTRAST	.033	1	.033	3.25*
A X B	.024	2	.014	1.17
D'(A)	.025	1	.025	2.40
Z(K)	.000	1	.000	.01
DA x ZK	.033	2	.016	1.62
ERROR	.437	42	.010	

BETA WEIGHTS
D(A) -.04
Z(K) .00

**p = .01
*p = .07

Effect of Experimental Instructions and Target-to-Background Contrast

The effect of instructions in this experiment was fairly clear cut, with a different pattern of results for reaction time and the number of hits. The accuracy and neutral instructional groups had similar reaction times which were significantly slower than the responses of the speed instructional group. However, the similarity between the accuracy and neutral groups changed when the frequency of hits was considered. In this case, the hits of the neutral group were fewer than those of the accuracy group and approached the results of the speed group which had the least number of hits. The results are even more interesting when the frequency of false alarms is considered. In this case all of the instructional groups had the same number of false alarms, except at low contrast when the number of false alarms for the accuracy group did not significantly increase as they did for the results of the speed and neutral groups. Thus it appears that the accuracy instruction is superior to either of the other instructions, when the increase in the number of hits and the fewer number of false alarms are considered. This gain more than offsets the increase in response time of about 4 seconds. The emphasis on accuracy appears to be as important as additional time, since the neutral group did not do as well while taking the same amount of time.

The next interesting finding was the similarity of the differences in reaction times between the instructional groups across the response categories of hit, miss, false alarm, and correct reject. The patterns of reaction times for the three latter categories were similar and all were consistently slower than the reaction times for hits. It appears, as a result, that the response set introduced by instruction was sufficiently strong as to be pervasive. The aviators in the different instructional groups apparently adopted a consistent pattern of response time. When no target is present, as in the case of misses, correct rejects and false alarms, the same time pattern was used. It became systematically more rapid, however, when targets were present. The similarity of the response times for false alarms to correct rejects and misses is of some interest. It shows that a false alarm is an uncertain response comparable to the decision that no target is present.

Contrast, like instruction, also had a consistent effect on the dependent variables of reaction time and frequency. In general, reaction times increased and the frequency of hits decreased for low contrast as one would expect. The unexpected finding was the interaction of the accuracy instruction with false alarms at low contrast. The accuracy group apparently took the extra care needed to avoid false alarms under the more difficult condition of low contrast. It had approximately the same response time, however, as the neutral group.

Effectiveness of Signal Detection Model

Although the signal detection model provided a reasonable fit to the data of this experiment, several factors were introduced which affected the precision of the model. The first factor was the use of Army aviators, who are highly selected (intelligence and physical qualifications), highly trained, and highly experienced. Their flight training includes surveillance techniques. In addition, many of the officers and warrant officers had extensive combat experience in Vietnam with emphasis on target search. In addition, these individuals appear to have an attitude to excel. One aviator, in this respect, characterized himself and colleagues as "self-centered perfectionists." This appeared to lead to several response strategies such as the following:

a. Keeping count of the number of hits to account for 50% of the trials when targets would be present. (For this reason, as described previously, the instructions were modified for Experiment II.)

b. Removing their heads from the chin rest to positively identify the object seen, despite instructions to the contrary.

c. Changing their confidence level if the target did not fall near the matrix number (changed after the pilot studies as described previously).

In addition, the aviators questioned the confidence levels, claiming that in actuality they could never be sure that a target was "positively not there" as implied by confidence level 1, or even "probably not there" as implied by confidence level 2. Others even felt that confidence level 3 could be interpreted to mean that a target was probably there, but not necessarily a tank. In addition, to the above factors which influenced the distribution of confidence levels, the aviators also were detecting and pausing to identify whether the detected object was a tank. All of the above considerations contributed to fewer false alarms.

One other characteristic of the pilots may have influenced the role of instructions. This was their statement that they normally stressed accuracy, and as a result found the neutral and speed instructions counter to their natural set. The significant main effects found for this independent variable, however, indicates that their "natural" response set did not nullify the instructional set, although the instructional effects may have been reduced. Some of the pilots also remarked that their pattern of results would probably be different if it had been a field situation. Due to stress and the task of flying an aircraft, they consequently would have had less time to concentrate than they did in the present situation.

Another factor contributing to fewer false alarms than might be encountered in the typical signal detection experiment, was the use of a tank target against natural countryside. The tank is angular with a

protruding barrel, in contrast to the more rounded shapes found in nature. Some of the aviators also felt that the tank was in sharper focus. One aviator felt that the tank had a slightly different hue than other objects (probably due to the uniformity of light distribution across it). In effect, it was "hard to mistake something for a tank." This factor probably led to fewer false alarms and a higher number of hits than would be normally encountered at the same contrast conditions.

The 30" exposure time also contributed to fewer false alarms, by allowing the aviators more time to scan and interpret the viewed scene. The allowed time, however, is typical of the time that would be allowed under field conditions, as described previously.

The above factors probably contributed to the lack of equal variance between the noise and signal distributions as discussed in the Results chapter, by distorting the variability of the observers' responses. The major contributor, however, to the lack of reliability of the signal detection parameters, as determined by the chi-square values that were found to be significant for approximately 50% of the aviators was the contrast levels used. As discussed previously, contrast values of approximately 17% and 40% were used. These are values typically used in laboratory and field target acquisition experiments, respectively. Each of these values, as disparate as they were, was too hard for some subjects and too easy for others. The validity of the signal detection model depends upon near threshold stimuli to meet its underlying assumptions. The wide variability of subject capabilities about the contrast levels selected reduced its reliability. In effect, the full value of the model for target acquisition experiments will depend upon the setting of individual threshold levels for each subject. This is practically impossible for field studies, and would further increase the difficulty of using the model in laboratory experiments (in addition to requiring scenes without targets, and requiring a larger number of trials than typically used).

The occurrence of false alarms in the signal plus noise trials represents still another departure from the typical signal detection experiment. Consideration was given to discarding them, or adding them to the miss category. However, the option selected of adding them to the normal false alarm category seemed reasonable and did not appear to detract from the results. In some studies it may also be possible to use these events alone, without the presentation of a noise only condition. This aspect, however, warrants additional study. The use of false alarms as a dependent measure, without calculation of signal detection parameters, also adds a meaningful response dimension in itself which is not usually considered in target acquisition studies.

Other factors detracting from the reliability of the signal detection model include the averaging of the signal detection parameters and the relatively small number of trials per subject. The number of trials, however, seemed adequate in this application, particularly when the two

contrast levels were combined for each experiment. As discussed earlier, the number of trials used in this experiment was partly determined by the goal to test each subject for a period of time no longer than 4 hours. Despite all of the above-mentioned problems, the model yielded a reasonable representation of the effects of both contrast and instruction variables on both sensitivity (D(A)) and response bias (Z(K)) as discussed below.

A fundamental issue that had to be considered before an analysis of the relationship between the signal detection parameters (D(A)) and Z(K)) and the conventional dependent measures of reaction time and frequency was the additivity of these two different types of measures. The question basically is whether the effects of bias and sensitivity add in a systematic way to the conventional response measures of reaction time and frequency, thereby facilitating the removal of their effects by analysis of covariance. The two major problems are interaction and the nonlinearity of the effects (S. Sternberg, 1969). As described in the Results chapter, neither of these factors occurred to complicate the analysis of the data. The only exception was the interaction of the accuracy instruction with contrast for false alarms. This relationship, however, was not treated directly insofar as the adjustment procedures were limited to the reaction time and frequency of hits.

Before a discussion of the signal detection parameters is undertaken, a review of the factors affecting the reliability of the model in the present study is warranted. These, briefly summarized, were as follows:

1. The use of simulated field conditions and procedures departed from the strict laboratory threshold type of experiment that is typically used.

2. The distortion of the false alarm rate relative to the hit rate due to target conspicuity, a relatively long exposure time, and strategies on the part of the aviators to minimize false alarms.

3. The averaging of the signal detection parameters when they are typically used to describe the performance of a single individual.

These factors affected the two basic assumptions of the signal detection model regarding the normality and equal variances of the noise and signal distributions (Appendix C). The standard deviations of the noise and the signal plus noise distributions were not equal. As described elsewhere, this problem was compensated for by the calculation of D(A). However, the lack of equal variability contributed to the correlation between D(A) and Z(K). The statistically significant chi-square values implied that the response distributions of some of the observers were not normally distributed. The linearity of the ROC curves, however, based on Z transformations, indicate that the average signal detection

parameters were normally distributed. The model was, in view of these considerations, able to produce ROC curves consistent with the expectations for the independent variables. Specifically:

1. It readily portrayed the higher response sensitivity associated with higher contrast (Figures 17 and 19).

2. It portrayed the higher sensitivity associated with the three instructional levels (Figure 19).

3. It differentiated the bias effect associated with each instruction level (Table 50).

The above ROC curves reflect the significant relationship between D(A) and contrast as expected, and the systematic relationship between D(A) and instruction although not significant ($p = .17$). The latter can be attributed to the increasing number of hits as a function of instruction. In this respect, the plot of D(A) values (Figure 12) is equivalent to the plot of frequency values (Figure 2). In addition, the relationship of the three instructional values in these figures is the same as those for their ROC curves (Figure 19). This highlights the primary dependence of both D(A) and the ROC curves on the frequency of hits.

While Z(K) was influenced by instruction, the relationship was not significant ($p = .0556$). This did not prevent the formula for the ROC curves, however, from discriminating between each of the instructional sets in a systematic and logical manner (Table 50). In addition, the interaction found for Z(K) in Figure 10, though not statistically significant, was not reflected in these results. In addition to the above relationship of Z(K) with instruction, Z(K) was significantly influenced by contrast. This could be attributed to the large difference in contrast values which changed the confidence with which the subjects responded.

Adjustment of Reaction Time and Frequency of Hit Measures

This section explains the reason for the results of the analysis of covariance which adjusted for the effects of hits rather than reaction time. It is apparent from the results of the regression analyses that D(A) is the signal detection parameter which is most related to the frequency of hits as a function of instructional differences and contrast, and consequently was able to partial out the effects of these latter variables in the analysis of covariance. Z(K) showed less correlation with the frequency of hits and was correlated with D(A). As a result, it accounted for only a small percentage of the variance removed in the analyses of covariance. D(A) and Z(K) on the other hand had little relationship to reaction time, and consequently had little if any effect in the analysis of covariance.

The ability of the D(A) variable to also adjust for the effects of instruction, despite the lack of significant relationship with this variable, is of some interest. This can be explained by the fact that D(A) is primarily a function of the frequency of hits. It consequently has an intrinsic correlation with hits which need not be statistically significant to be effective. The negligible impact of Z(K) in the analysis of covariance, despite its main effects with contrast, may be due to the fact that Z(K) is essentially a ratio of false alarms to hits. As such, Z(K) varies about a given D(A) value (i.e., it is a point on ROC curve). This helps to explain its lesser correlation with hits unlike D(A). In effect, D(A) is logically the more powerful predictor due to its primary statistical dependence on the frequency of hits.

The surprising finding is the robustness of the D(A) measure despite the generally low reliability of the signal detection data. Its primary statistical relationship to the frequency of hits apparently makes it a powerful covariate. As the above analyses showed, it can be used to adjust for the differences of instructional set as well as contrast. For the same reason, it should adjust for the effects of any independent variable that affects the frequency of hits, which will detract from its utility when competing sensors are compared.

The lack of a positive relationship between D(A) and reaction time is understandable, when one considers the lack of correlation between reaction time and the frequency of hits and the positive relationship of D(A) with the latter. This is supported by the finding that, while the accuracy and speed groups had similar reaction times, they had a dissimilar number of hits and false alarms.

In addition to the use of analyses of covariance to partial out the effects of instructional set and contrast, the adjusted data of any given observer can also be predicted by the following formula:

$$\text{Hits} = A + A_1\, D(A) + A_2\, Z(K),$$

where A_1 and A_2 are beta weights, and A_o is the constant. These values would be obtained from a regression analysis. In such an analysis, one has the option to use the beta weights and constants calculated for the individual experiment rather than from the pooled data as used in the two-way analysis of covariance reported above. In such an application, the predicted hits for the subject would be subtracted from his actual hits to obtain his adjusted value. It would then be possible to pool the adjusted values of each subject and to conduct another two-way analysis of variance to determine whether the main effects have been removed.

Conclusions

1. Instructional set is an important determinant of aviator performance during target acquisition with respect to reaction time and the number of hits, which confounds the results of similar experiments when this variable is left uncontrolled.

   (a) An instructional set which emphasizes the accuracy of response leads to more hits and fewer false alarms in the same amount of response time as undirected (or neutral) instructions, and requires only 3 to 4 more seconds of response time than an instructional set which emphasizes speed of response.

   (b) The effect of an instructional response set is sufficiently pervasive as to effect the reaction times of different instructions for false alarms, misses, and correct rejections in the same relative pattern as those for hits, except for being longer in time.

   (c) A false alarm represents a less certain response on the part of the observer, since its reaction time is the same as that for the decision of no target (miss or correct rejection).

2. The signal detection model provides a reasonable representation of the sensitivity and bias effects associated with instructional set and target contrast, with some loss of precision due to its application under simulated "field" conditions.

   (a) The reliability of the signal detection model in target acquisition studies will increase to the degree that the contrast values of the targets approach the threshold of each subject.

   (b) The signal detection model, when used in an applied problem area such as target acquisition, requires a large increase in the number of experimental trials for purposes of statistical reliability and due to the need to use scenes with and without targets.

3. The signal detection parameters associated with sensitivity and bias can be successfully used to adjust the frequency of hits between target acquisition studies, to remove the effects of different instructional sets as well as different contrast levels.

   (a) The signal detection parameter for sensitivity (D(A)) represents the primary covariate for the adjustment of hits due to its primary statistical dependence on the frequency of hits, with the parameter for bias (Z(K)) playing a lesser role due to its primary statistical dependence on the ratio of false alarms to hits.

(b) The intrinsic relationship between D(A) and hits will limit the value of D(A) as a covariate to remove the effects of undesired variables since it will remove the effects of any independent variable (such as competing sensors) that affect the number of hits.

(c) The signal detection parameters do not adjust for the differences in reaction time. This is due to the dependence of the model on frequency of hits and false alarms, and the lack of correlation of these measures with reaction time.

SUMMARY

Purpose

The purpose of this study was to apply the principles of the theory of signal detection to a target acquisition experiment which involved three types of instructions and two levels of target-to-background contrast, and to evaluate the utility of its statistical parameters when used to adjust the responses (reaction time and number of hits) of the test participants to a comparable level of performance which is free of the effects of response bias that was introduced by the type of instructions.

Background

Target acquisition is a difficult and complex human task where the role of an observer's response bias as a result of experimental instructions is not fully understood or appreciated. This variable has been left uncontrolled in what otherwise can be considered sophisticated laboratory and field experiments. The results of such experiments are frequently inconsistent with one another, which in part may be due to the use and effect of different instructions that are given to the test participants.

The theory of signal detectability appears suited for the investigation of this problem area. It postulates that an observer has a continuum of response states rather than a discrete sensory threshold to a stimulus. In doing so, it makes an explicit distinction between two characteristics of an observer's response, i.e., (1) his sensitivity to the stimulus (d'), and (2) his prevailing response bias (Beta). As such, it questions the validity of classical sensory thresholds, and views them as misleading, since they do not account for the latter.

Time to detection and the number of hits are the usual dependent measures of a target acquisition experiment. They can also be considered to be operationally relevant measures, which are compared between different experiments. The d' and Beta values of a signal detection experiment, as dependent measures, are usually evaluated in and of themselves without comparison to other dependent variables. Moreover, it is difficult to evaluate the implications of these measures relative to the operationally relevant dependent measures that may be associated with them. The direct evaluation of these latter measures, when free of response bias, would have more utility than information on d' and Beta alone or when used in conjunction with them. In effect, a capability is needed to transform operationally relevant measures to a bias free level. The utility of the signal detection parameters to accomplish this objective warrants investigation. If successful, this would permit the direct comparability of data between experiments which differ in instruction and other utility variables.

Hypotheses and Experimental Goal

1. Target acquisition performance (reaction time and number of hits) will differ as a function of the type of instruction and level of target to background contrast given to the test participants.

2. The signal detection parameters of Beta and d' will reflect the effects of the different instructional levels and target-to-background contrast, respectively.

3. To evaluate the utility of the signal detection parameters of Beta and d', when used in an analysis of covariance to adjust the operationally relevant dependent measures to a bias-free level of performance.

Method

A two-factor experiment involving three levels of instruction and two levels of target-to-background contrast was employed. Twelve Army helicopter pilots were assigned to each instructional level, with target-to-background contrast as a within factor. The design was presented in the form of a 4 x 4 Latin Square to assure experimental control of the effects of trial sequence, target background, and the order of presentation of target-to-background contrast. The above design was repeated in a second experiment which changed only the levels of target-to-background contrast, and which used different test participants. In the first experiment, contrast levels typical of field studies (35% and 45%) were used; while in the second experiment, contrast levels typical of laboratory tests (14% and 17%) were used.

A target acquisition task during a simulated helicopter pop-up maneuver at 1000 feet altitude was presented, with a 30-second exposure time. The observer's task was to search for a single 20-foot military tank in various field locations, and at a slant range of 2500 feet. An infra-red scene of European terrain was simulated, which was presented on a 50 x 50 degree backlighted screen viewed at 20 inches. The scenes were presented with and without targets, in order to obtain an observer's hit rate and false alarm rate, the basic procedural requirement of signal detection theory.

Data Analysis

Analyses of variance conducted for the Latin Square design of the first experiment indicated no significant differences associated with the presentation order of experimental stimuli, plus the lack of a significant difference between the two contrast levels. It was possible as a result to combine the data of the first and second experiments for the conduct of a two by three analysis of variance (contrast x instruction),

with contrast as a between factor. Analyses were conducted for eight dependent variables, which involved the combination of reaction time and frequency of response with respect to hits, false alarms, misses, and correct rejects.

The signal detection parameters of each observer were calculated. D(A) rather than d' was used in this analysis due to the lack of equal variances between the noise and signal plus noise distributions. The signal detection parameters of the subjects were then averaged to serve as input to another two by three analysis of variance. The dependent variables in this analysis were D(A), Beta, and their associated signal detection parameters of A(Y-intercept), B(slope), Delta M, and Z(K). The latter is another measure for bias in standard scores, and was used in place of Beta in the subsequent analyses due to the distortion of the Beta values when averaged.

The relationship between reaction time and the number of hits to D(A) and Z(K) were tested by means of regression analyses. These latter two variables were then used as covariates in a two-way analysis of covariance conducted separately for reaction time and the number of hits.

Results and Conclusions

1. Instructional set is an important determinant of aviator performance during target acquisition with respect to reaction time and the number of hits, which confounds the results of similar experiments when this variable is left uncontrolled.

2. The signal detection model provides a reasonable representation of the sensitivity and bias effects associated with instructional set and target contrast, with some loss of precision due to its application under simulated "field" conditions.

3. The signal detection parameters associated with sensitivity and bias can be used in an analysis of covariance to adjust the frequency of hits between target acquisition studies, to remove the effects of different instructional sets as well as different contrast levels. For the same reason, however, they would also remove the difference in the number of hits due to different sensor systems.

APPENDIX A

DESCRIPTION OF SIGNAL DETECTION THEORY

TSD assesses an operator's response bias relative to his willingness to say "yes," as manifested by the operator's correct and false detections (hit rate (HR) and false alarm rate (FAR), respectively). This calls for the use of blank stimuli in an experiment (i.e., a trial without a signal or "noise" only). In this way, a subject is never sure that a stimulus is present (and can never be correct by simply saying yes with his eyes shut). Thus, if a subject says yes for a stimulus when only noise is present, a FAR can be calculated for the blank stimuli.

The blank trials are usually 50% of the total trials presented to the subject, to allow HR and FAR to be equally reliably estimated. It is the ratio of the hits (HR) when the signal is present to the false alarms (FAR) when the signal is absent (i.e., noise only) that determines the subject's sensitivity (d'). Thus, a subject whose "yes" responses produce primarily hits and few false alarms would demonstrate high sensitivity. The number of response alternatives is shown in Figure 27. Since the bottom row of this figure is a complement of the top row, only the hit and false alarm rates need be reported.

		Stimulus	
		Present	Absent
Response	Yes	Hit	False alarm
	No	Miss	Correct reject

Figure 27. Matrix of response outcomes.

The hypothetical distribution of a subject's responses for the blank stimuli (noise only) and for the stimuli with a target is shown in Figure 28. The response distribution for noise alone (as shown in the left hand portion) should be normally distributed. With signal added, the strength of the response distribution should increase and move to the right. The degree of separation between the two distributions would be a function of the strength of the signal. The separation of the two distributions is given in standard deviation units with the mean of the noise distribution defined as zero. A sensitivity of 1.0 implies that the mean of the signal plus noise distribution is shifted one standard deviation to the right of the noise distribution.

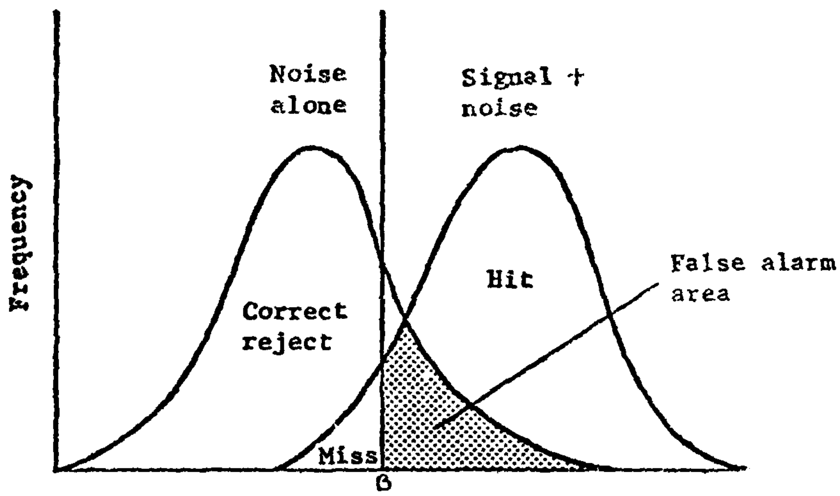

Figure 28. Hypothetical distribution of subjective internal response produced by two types of experimental trials.

During the conduct of an experiment, with the alternate and random presentation of trials with and without a signal, the subject cannot readily tell whether a signal is present. He is forced to make a decision. According to decision theory, he will respond relative to an internal criterion (i.e., Beta). This criterion level is illustrated by the vertical line marked B in Figure 28. The shaded portion of the noise curve to the right of the criterion line represents the FAR. The unshaded portion of the signal plus noise curve to the right of the criterion line represents the hit rate. As observer caution

increases, the criterion line will shift to the right reducing both the FAR and HR. Thus, for a given change in Beta, the hit and false alarm rates will both change, but their values will still represent the same sensitivity. On the other hand, if there is a change in the subject's sensitivity, there will be a change in hit rate only, without a change in the FAR (i.e., the response distributions will move further apart). In effect, the way in which HR and FAR change implies whether a change in sensitivity (d') or response criterion (Beta) or both has occurred. Probability tables exist which assume equal variance between the noise and signal and noise distributions to aid this interpretation, as well as the degree of separation between the two distributions and the location of the criterion line along the abscissa. The response criterion or Beta is defined in terms of the ratio of the heights (i.e., probability density) of the noise curve and the signal and noise curves along which it is located. A criterion of 1.0 would be at the position where the two curves cross and, in effect, would represent no bias. For a stringent criterion level, the ordinate of the signal-plus-noise curve at the criterion line is much higher than the ordinate of the noise alone curve. By means of the above logic, a technique is thus available to separate the confounding influence of response bias from a subject's sensitivity.

The values of the HR and FAR for any given bias level when plotted yield what is called the receiver operating characteristic curve or ROC curve, which completely describes the HR and FAR possible for a given sensitivity as a subject changes response bias. The curve is illustrated in Figure 29. Each curve represents a different sensitivity, and each point on the curve represents a different bias. In other words, each separate curve along its entire length represents a different d' value. Any point on a given curve represents a bias level. The d' and beta values in this context are independent statistics. The diagonal line in this figure is the expected ROC curve if the receiver responded randomly. Any point along the line reflects a bias for saying yes. Thus, if a person says yes randomly, 50% of the time, his HR and FAR would be 50%, when the signal is present and not present, respectively. This diagonal, as a result, is the limiting ROC curve as the signal distribution approaches the noise distribution.

In addition to descriptive utilization as described above, TSD can also be used in a normative way by means of the concept of an ideal receiver. This concept is based on energy characteristics of the noise and signal distributions which are both normal and have the same variance. The log likelihoods of normal distributions are also normal, and by being normal distributions they are completely described by their mean and variance. Utilizing Shannon's sampling theorem (Grabbe & Woolridge, 1958), the physical properties of the noise and signal are related to the means and variances of the log likelihood distributions for signal and noise. The difference between the means of these distributions is 2E/No, which is also their variance. Hence the highest value of d' that an observer could achieve <u>given</u> the described characteristics of signal and noise is d' opt = $\sqrt{2E/No}$ (i.e., a function of

the signal to noise ratio). In effect, there is an optimum balance of hit and false alarm rates (or B) for a signal of a given strength. In this respect, the ideal receiver is not one that makes 100% HR and no FAR, but one that utilizes the available information most efficiently. In other words, the ideal observer is an observer who can hold a constant bias and is exactly confident of his decision criterion. His performance, as a result, represents a theoretical limit.

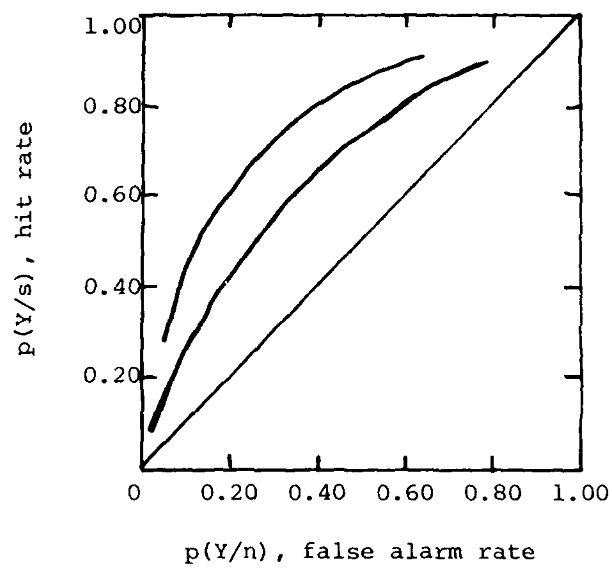

Figure 29. Receiver operating characteristics curve.

The application of the concept of the ideal observer, however, in the above manner requires the use of highly controlled noise and signal distributions and knowledge of their energy distributions. The performance of the ideal receiver can only be calculated relative to such information. For applied problem areas, where such information is lacking, the concept of the ideal observer has less power. In such cases, the ROC curve with the highest d' value becomes the best representation of the ideal receiver, but not "ideal" in the classical sense. In effect, the data of the experiment define their own normative base for comparison of individual or treatment differences. The question then becomes, in an empirical sense, which variables cause the subject or subjects to operate at the highest level of efficiency? This can be answered most efficiently by inspection of the group ROC curves.

APPENDIX B

INSTRUCTIONS GIVEN TO SUBJECTS

General Experimental Instructions (R)

You will be a test participant in a simulated target acquisition task from a helicopter. A pop-up maneuver will be presented allowing you to have 30 seconds to search for the target. The view will be the same as you would expect to see at 1000' altitude and a 2500' viewing slant range. The target that you will be searching for will be a 20' armored tank. It will be presented against different background scenes and in different locations.

A simulated "FLIR"* sensor is being used so that warm areas will look white and cool areas dark. Hence, the tank and trees will be "white" as compared to the "dark" fields. The tank will have varying degrees of brightness contrast depending upon its location and amount of heat radiated. The tank will be present in the scene on a random basis. Your display will be a 20" x 20" backlighted screen. When viewed at 20" it will present a 50° field of view. Your task will be to search for one tank in the viewed scene and to signal when you have decided whether the target is present or absent. After your signal on the response panel, or after 30 seconds, the scene will disappear and a matrix of 64 squares and numbers will appear on the screen. You will be asked to indicate the corresponding location of the target on the response panel. Please enter 0C if your decision was no tank. In case you have made no decision in 30 seconds, and the background scene goes off, please guess and indicate where the target might have been, or enter 00 if you guess there was no tank. For each decision of target or no target you will be also asked to rate whether in your opinion the target was positively there or only probably there, and similarly whether the target was positively not there or probably not there. The decision and corresponding response buttons are as follows:

1. No target--positively not there
2. No target--probably not there
3. Target--probably there
4. Target--positively there

This information is labeled on your response panel.

The data we are collecting are to determine basic human performance capabilities under varying field conditions. Your data as a result will be anonymous. We will be pleased, however, to give you a personal

---

*Forward Looking Infrared

debriefing if you so please immediately after the experiment. Do you have any questions at this point?

You will be given 25 practice trials to familiarize you with the overall task and procedures. After the above trials, the formal experiment will begin. You will receive a total of 140 scenes, which will be presented in five blocks with short rest intervals in between. During the experiment, pertinent instructions will be repeated to you.

Thank you for your cooperation.

INSTRUCTIONS

Practice Session (R)

You will now be given 25 practice trials. Each of these scenes will have a target present. Your task is to search the viewed scene and to signal when you have located the target. Each scene will be presented for a maximum of 30 seconds. When you have made your decision please press the signal button at the bottom of the response panel. This will cause the presentation of a numbered matrix in place of the viewed scene. Select the two-digit number (e.g., 06) closest to where you saw the target and enter the coordinates by means of the numbers (1-10) located at the top of response panel. Please remove your head from the headrest if it will help you to see the numbers on the response panel. After this action please enter the confidence you have in your response by means of the second row of labeled numbers. The recording computer cannot accept your response unless the above sequence is followed. A green indicator light will go on if your entries are being recorded. In case you change your mind about target location please enter the new two digit number before proceeding to your confidence response. If necessary the experimenter will point out the correct target to you after each scene. If possible please keep your left hand on or near the signal button.

Remember:

- Please press the detect button when you have made your decision.
- Enter a double digit target location number from the display matrix, or 00 if no target is present.
- Enter your confidence rating.
- If 30 seconds have elapsed and you have made no response please guess as to whether the target was present or absent and enter the appropriate coordinate numbers and confidence level.
- Please indicate the certainty of your decision as follows:

  1. No target--positively not there
  2. No target--probably not there
  3. Target--probably there
  4. Target--positively there

INSTRUCTIONS

Experimental Group I

The experiment is about to begin. As described to you earlier the target may or may not be in the viewed scene. Your task is to search the viewed scene and to decide whether a target is present or absent. Each scene will be presented for a maximum of 30 seconds. An auditory signal will be presented after 15 and 25 seconds have elapsed.

Remember:

- It is equally important to decide whether a target is present or absent.
- Please press the signal button when you have made your decision.
- Enter a double digit target location number from the display matrix, or 00 if no target is present.
- Enter your confidence rating.
- If 30 seconds have elapsed and you have made no response please guess as to whether the target was present or absent and enter the appropriate coordinate numbers and confidence level.
- Please indicate the certainty of your decision as follows:

  1. No target--positively not there
  2. No target--probably not there
  3. Target--probably there
  4. Target--positively there

INSTRUCTIONS

Experimental Group II

The experiment is about to begin. As described to you earlier the target may or may not be present in the viewed scene. Your task is to search the viewed scene and to decide whether a target is present or absent as rapidly as you can. A rapid response is essential in order to avoid detection and exposure to enemy fire. Use as little of the available 30-second search time as feasible to assure the speed of your decision as to whether the target is present or absent. An auditory signal will be presented after 15 and 25 seconds have elapsed to alert you to your increasing jeopardy.

Remember:

- It is equally important to decide whether a target is present or absent.
- Please press the signal button when you have made your decision.
- Enter a double digit target location number from the display matrix, or 00 if no target is present.
- Enter your confidence rating.
- If 30 seconds have elapsed please guess and enter the correct coordinate numbers and confidence level.
- Please indicate the certainty of your decision as follows:

  1. No target--positively not there
  2. No target--probably not there
  3. Target--probably there
  4. Target--positively there

INSTRUCTIONS

Experimental Group III

The experiment is about to begin. As described to you earlier the target may or may not be in the viewed scene. Your task is to search the viewed scene and to decide whether a target is present or absent as accurately as you can. An accurate response is essential in order to reliably alert supporting forces, and to minimize additional pop-up maneuvers. Use as much of the available 30-second exposure time as feasible to assure the accuracy of your decision as to whether the target is present or absent. An auditory signal will be presented after 15 and 25 seconds have elapsed to assure the accuracy of your response in the time remaining.

Remember:

- It is equally important to decide whether a target is present or absent.
- Please press the signal button when you have made your decision.
- Enter a double digit target location number from the display matrix, or 00 if no target is present.
- Enter your confidence rating.
- If 30 seconds have elapsed and you have made no response please guess as to whether the target was present or absent and enter the appropriate correct coordinate and confidence level.
- Please indicate the certainty of your decision as follows:

  1. No target--positively not there
  2. No target--probably not there
  3. Target--probably there
  4. Target--positively there

APPENDIX C

STATISTICAL PROCEDURES FOR CALCULATING SIGNAL DETECTION PARAMETERS*

TSD is an individual model. Each individual's TSD parameter of d' and Beta must be calculated from his HR-FAR. The d' and Beta values can be treated statistically like any other dependent variable, with the same meaning attributable to their derived values (e.g., means and standard deviations). On the other hand, averaging of HR-FAR values would lead to distortion and perhaps the loss of any rank order equivalents in the data.

Prior to the description of the analysis procedures required for the TSD parameters, two basic assumptions of the TSD model should be made clear due to their implication for the procedures followed.

1. It is assumed that the noise and signal distributions are normally distributed. This provides the rationale for the use of Z transformations, and the particular statistical regression techniques that are employed for calculating the slope of the ROC curve. A chi-square test of this assumption is described later.

2. It is assumed that each individual's noise and signal distributions have equal variances for the calculation of the d' measure. d' values calculated without assurance of equal variance are subject to appreciable error. A procedure is described which permits the calculation of each subject's distribution variance. A procedure is also described below for the calculation of a sensitivity index, D(A), which avoids the problem for d' introduced by unequal variances. The variance of the noise distribution is always assumed to be 1 with a mean of 0.

A subject's response distribution variance can be determined from the slope of his ROC curve, as described later. A ROC curve could be plotted from a single HR-FAR pair if the variance of the subject's response distribution to a signal is known or can be reliably assumed. Since in the present case, the subject's variance is not known, three HR-FAR pairs will be necessary to calculate a reliable ROC curve. As noted previously, bias will be a function of instructions. In the present study, only one instructional level will be given to a subject to avoid the problem of confounding instructions. As a result, a technique is necessary to obtain three bias levels for a single subject operating under one instructional level. This will be achieved by the use of a confidence rating scale. As described previously, the subject

---

*The author is indebted to Dr. Lewis Harvey at Colorado University for describing these procedures.

will respond to each stimulus, with a yes or no (i.e., signal present or absent). For each of these response categories, he will reply "very sure" or just "sure." As a result, the following four response alternatives will be available whether a signal or only noise is actually presented.

1. No target--positively not there
2. No target--probably not there
3. Target--probably there
4. Target--positively there

When calculating a ROC curve, the four options reduce to three bias points as will be pointed out below when cumulative probabilities are discussed. It should be made apparent at this point that the use of confidence ratings changes the HR-FAR measures into the four confidence intervals shown above.

As a result of the above rating approach, it will be feasible to plot a ROC curve for each subject. The slope of the curve will permit the calculation of the signal distribution's standard deviation for each individual. Consequently, it will not be necessary to assume equal variances between the signal and noise distributions to calculate the d' measure. The specific measure of sensitivity, D(A), will be based upon the actual variance obtained.

1. Calculation of TSD parameters

The specific analysis procedures based on the frequency of the <u>individual</u> subject's responses to the above confidence intervals is now described:

a. Tabulation of Response Frequencies

The frequency of a subject's response for each confidence interval relative to the signal and noise conditions is plotted. It should be recalled that each condition is presented 30 times. This is illustrated in Figure 30.

b. Calculation of Response Probabilities

These are the above frequencies, each divided by the number of signal and the number of blank trials (i.e., 30).

c. Cumulative Probabilities

These are the cumulative probabilities calculated by successively adding the above response probabilities starting with the highest criterion (category 4). Since the last pair of probabilities is 1.00, they are not usually presented on the normally plotted ROC curve. They cannot be plotted in Z score scales because there is no Z score corresponding to 1.0 (or 00). In effect, a four category response scale gives

a. Frequency

	Signal	Noise
4.	19	3
3.	5	7
2.	4	11
1.	2	9
	30	30

b. Probability

	Signal	Noise
4.	0.6333	0.1000
3.	0.1667	0.2333
2.	0.1333	0.3667
1.	0.0667	0.3000
	1.0000	1.0000

c. Cumulative Probability

	HR	FAR
4.	0.6333	0.1000
3.	0.8000	0.3333
2.	0.9333	0.7000
1.	1.0000	1.0000

d. Z Score Cumulative Probability

	HR	FAR
4.	0.3403	-1.2817
3.	0.8415	-0.4303
2.	1.5014	0.5240
1.		

Figure 30. Conversion of confidence ratings to HR-FAR values.

rise to 3 probability pairs (i.e., N-1). These pairs are the values plotted to form the ROC curve as shown in Figure 31.

d. Cumulative Z-Score Probabilities

These are the Z-score transforms of the above cumulative probabilities based on the assumption of a normal distribution (where u = 0, and G (Sigma) = 1.0). Negative Z-scores correspond to probabilities less than 0.5, according to standard statistical convention. This is illustrated in Figure 32.

It can be seen in Figure 32 that the ROC curve is now a straight line. This is a consequence of the theorem's assumption that the noise and signal distributions are normally distributed. As a result, the prediction is that the ROC curve becomes a straight line when plotted in Z coordinates. How well the data fit this linear model can be determined by chi-square, as a "goodness-of-fit" measure. If the final value of chi-square is not statistically significant (i.e., at the .05 level of confidence), we can conclude that the signal detection model provides a satisfactory description of the performance in the rating scale signal detection experiment. Otherwise, it does not account for all the variance in the data. In this case the utility and power of the model are reduced for the individual case.

Due to the assumption of a normal distribution and the ROC curve in Z scores forms a straight line, the relationship between HR_Z and FAR_Z can be describe as follows:

$$HR_z = a + b \cdot FAR_z$$

This formula is merely the formula for a straight line where:

$$Y = a + b \cdot X$$

It should be noted here that the ROC slope for the Z transformations will be a straight line even if the variances of the noise and signal distribution are not equal. In this case, however, the line will be oblique to rather than parallel to the diagonal as line shown in Figure 32 (i.e., will have a slope not equal to 1.0).

A primary purpose of the ROC curve is to determine the slope of the relationship between HR-FAR for the individual. Specifically, to determine the values of a and b in the formula:

$$HR_z = a + b \cdot FAR_z$$

where "a" is the Y intercept and "b" is the slope of the above function. The principal reason for using the Z transformation of values is that it

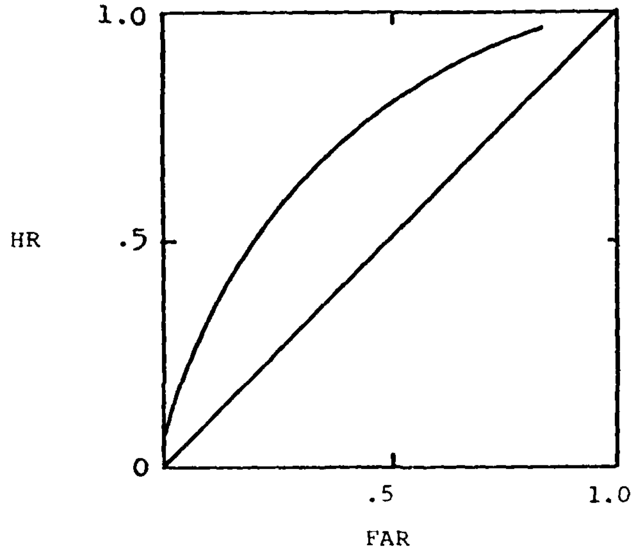

Figure 31. ROC curve based on individual responses to confidence rating scale.

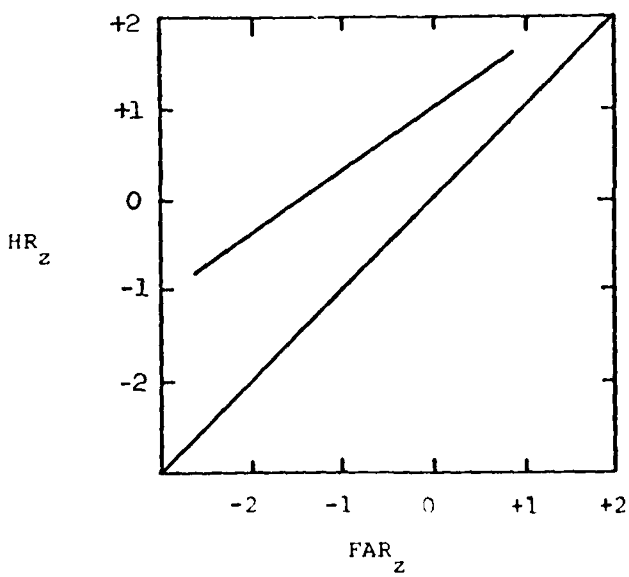

Figure 32. ROC curve based on Z transformations of HR-FAR values.

is easier to fit a curve to a straight line function. The values of "a" and "b" once obtained become the basis for calculating the specific TSD parameters of d' and Beta as will be explained.

Given a set of HR-FAR pairs, two techniques can be used to find the values of a and b for each individual in the above formula: (a) least squares and (b) the maximum likelihood technique. The least squares technique assumes that all variance is in the Y axis or HR_z. The maximum likelihood technique, on the other hand, takes into account the variance in both the HR_z and FAR_z axis as shown in Figure 33. This approach recommended by Dorfman (1969 and 1973) allows a more precise estimation of the parameters "a" and "b."

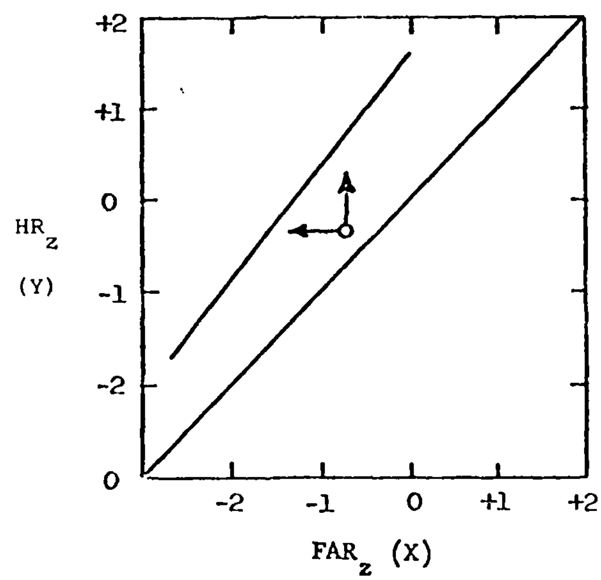

Figure 33. Illustration of maximum-likelihood technique in estimating variance for two axes (X and Y).

Once a and b are known, the subject's response distribution can be completely described in terms of its mean and standard deviation. Not only is b the slope of the above function, but it also represents the ratio of the standard deviation of the noise distribution to the standard deviation of the signal and noise distribution:

$$b = \frac{Gn}{Gsn}$$

$$Gsn = \frac{Gn}{b}$$

$$Gsn = \frac{1}{b}, \text{ since } Gn = 1 \text{ as given.}$$

As a result, the standard deviation of the signal + noise distribution is simply $\frac{1}{b}$. The mean of the signal + noise distribution is given by:

$$\text{Delta } M = \frac{a}{b}$$

which is the distance of the S+N mean from the noise mean, scaled in Gn units. Hence the noise and signal to noise distributions can now be characterized as follows:

Noise	Signal + Noise
M = 0	M = Delta M
G = 1.0	G = 1/b

With the above values, it is now possible to calculate the actual probability density functions of the assumed, two normal distributions of noise and signal + noise. The formal definition of a normal distribution is a function, f(x), of the following form:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\left[\frac{(x-\mu)^2}{(2\cdot\sigma^2)}\right]}$$

where μ = the mean of the normal distribution;
σ = the standard deviation of the normal distribution;
σ^2= the variance of the normal distribution;
e = 2.7183 (the base of natural logarithms)
π = 3.1416.

As noted, we assume that the mean of the noise distribution, $u_n = 0.0$ and its standard deviation, $G_n = 1.0$. The value of the function, f(x) (probability density), is plotted on the vertical axis, and the value of x (standard deviation units) is plotted on the horizontal axis. We can also draw the signal + noise curve by extending the horizontal axis to the right and plotting f(x) of a normal distribution whose mean, u_{sn} = Delta M and whose standard deviation, $G_{sn} = 1/B$.

With the noise and signal + noise distributions completely characterized, we are now in a position to calculate the d' and Beta values. As discussed previously, the sensitivity of the sensory process is characterized by the parameter d', the distance between the mean of the noise distribution and the mean of the signal + noise distribution, where:

$$d' = HR_z = FAR_z$$

The above formula is used only when the standard deviations of the noise and of the signal + noise distributions are equal, i.e., b = 1.0. Since in most experiments b is often not equal to 1.0, it is advisable to use a more general sensitivity parameter, D(A), that scales the distance between the two means in terms of a weighted average of the two standard deviations (Simpson & Fitter, 1973). D(A) is calculated from the values of a and b as follows:

$$D(A) = \left(\frac{2}{(1+b^2)}\right)^{\frac{1}{2}} \cdot a$$

Since $HR_z = a + b\ FAR_z$, then $A = HR_z - (B \cdot FAR_z)$, we get the following formula for D(A) based on HR-FAR pairs:

$$D(A) = \left(\frac{2}{(1+b^2)}\right)^{\frac{1}{2}} \cdot (HR_z - b \cdot FAR_z)$$

In this formula, b is the slope of the individual's regression line as calculated previously. It should be noted here that if b = 1, then D(A) = d' = Delta M.

The calculation of Beta or bias is a little more straightforward than the above procedure for the calculation of D(A). Beta is a likelihood ratio representing the subject's decision criterion. It is the ratio of the probability density of the noise and the signal to noise distribution along the decision criterion or likelihood ratio as illustrated in Figure 28. Because of the rating procedure, there will be three bias levels for each subject for each instructional set. The formula for Beta is as follows:

$$B = \frac{f\ (x)\ sn}{f\ (x)\ n}$$

The general formula for f (x) was described previously. In this case Beta is the ratio of the two vertical ordinates (one for the signal + noise distribution and one for the noise distribution) at the decision criterion point as mentioned above. We now have obtained for each individual the values of:

D(A): Detection sensitivity, least affected by unequal variances.

B1
B2
B3
The three decision criteria corresponding to the four response categories of the rating scale.

b: The slope of the ROC curve.

To recapitulate, the above values are obtained by the following interdependent steps:

1. Determination of three HR-FAR pairs using cumulative probabilities of a subject's confidence ratings given under signal and no signal trials.

2. Calculation of the cumulative Z-score probabilities for the above values and plotting of the ROC curve.

3. Determination of the values for the regression formula $HR_z = a + b \cdot FAR_z$.

4. Derivation of the characteristics of the noise and signal + noise distributions.

5. Calculation of the D(A) and Beta values.

A computer program is available for the above steps which was programmed by Donald Dorfman in 1969, modified by Lynn Beaver in 1972, and subsequently modified by Lewis Harvey in 1975 and 1977.

APPENDIX D

DESCRIPTION OF RSCORE PROGRAM

RSCORE - SIGNAL DETECTION RATING-SCALE ANALYSIS September 1977
Method of Dorfman and Alf

Programmed by Lewis O. Harvey, Jr.
Department of Psychology
University of Colorado
Boulder, Colorado 80309

This program takes confidence-rating data and, using the maximum-likelihood method, calculates the best estimates of the parameters of the signal detection model. These parameters include the mean and standard deviation of the signal plus noise distribution, the axis position of each of the decision criteria, the likelihood ratio (beta) of each decision criterion, and the detection index, d_a.

The program uses a form of the Newton-Raphson method called the method of scoring. In this method, the expected second partial derivatives are used rather than the observed second partial derivatives. The method of scoring requires initial estimates of the parameters. These estimates are obtained by the program by calculating the least-squares estimates of the parameters from the observed data. The least-squares estimates are then used as the input to an iterative procedure that calculates the maximum likelihood estimates. The iteration procedure stops when the sum of the absolute corrections of the parameters becomes less than 0.00. If the procedure does not converge on a solution within 200 iterations, a message will be printed out to that effect, and the current parameter values will be printed. The program checks for zero frequencies of response for each category on both signal and on noise trials. If such a pair of zero frequencies is found, the program will collapse these categories.

If only three response categories are used, or if only three response categories remain after collapsing of categories, the program obtains only the least-squares estimates of the parameters (further calculation of the maximum-likelihood estimates is not possible).

If only two response categories (e.g., "no" and "yes"), the program assumes that the signal plus noise and the noise distributions have standard deviations equal to 1.0. The remaining parameters are then calculated based on this assumption.

INPUT DATA

In its present form, the program will handle up to a nine-point rating scale. Two cards per set of data are required. All numbers must be integers and must be right-justified within their respective fields.

Card 1:	Columns 1-5	The number of categories in the rating scale (must be 9 or less). This number is mandatory.
	Columns 6-10	Subject number. This number is optional and for your convenience in identifying a particular set of data in the output.
	Column 15	0 (or blank), no output data written on TAPE4 1 causes output data to be written on TAPE4 (Note: After running RSCORE, the user must SAVE or DISPOSE local file TAPE4 using the appropriate KRONOS 2.1 commands. Otherwise, the information on TAPE4 will be lost at the end of the job.)
	Columns 16-80	Any alpha-numeric text. This text is optional and if included, will be printed out at the top of the data output. It is for your convenience in identifying a particular set of data.
Card 2:	Columns 1-4 Columns 5-8 Columns 9-12 Columns 13-16 etc.	The response frequencies appear in fields of 4, beginning with rating category "1" for noise trials and proceeding to the highest category for noise trials, followed by the response frequencies for signal trials beginning with the frequency of "1" and proceeding to the highest rating category. Thus, a 6-point scale will require 12 input numbers.
	Columns 73-80	Card identifier: not read by the program. For your use to identify the card in case you drop the deck.

The rating scale should be constructed such that confidence that the signal was present on a trial increases with the numerical value of the rating. For example: "1" = certain signal <u>not</u> present; "6" = certain signal <u>was</u> present. However the scale is constructed, the data must appear on card 2 in ascending confidence that the signal was present, first for noise trials, then for signal trials.

The number of successive analyses is unlimited. Just repeat cards 1 and 2 for each set of data. A blank card following the last data set will terminate the program.

PRINTED OUTPUT

Each set of data generates one page of printed output.

1. OUTPUT TITLE: Provided by the program.

2. DATA IDENTIFICATION: Information taken from CARD 1

3. TOTAL NUMBER OF NOISE TRIALS
   TOTAL NUMBER OF SIGNAL PLUS NOISE TRIALS
   These figures are calculated from the input frequencies provided on CARD 2.

4. RESPONSE FREQUENCIES: These are the raw frequencies of response for each of the response categories for noise (n) trials and for signal plus noise (s+n) trials. No collapsing of categories takes place. Check these numbers to make sure that you have made no errors in keypunching.

5. RESPONSE PROBABILITIES: These are the above frequencies each divided by the total number of noise trials (n) and the total number of signal trials (s+n). Collapsing of response categories has taken place.

6. CUMULATIVE PROBABILITIES: These are the cumulative probabilities calculated by successively adding the above response probabilities starting with the highest criterion response category (most certain that the signal was present). Each (n)-(s+n) pair at a given response category forms a FAR-HR pair. Noise trials generate False Alarm Rates (FAR) and Signal trials generate Hit Rates (HR). Since the leftmost pair of cumulative probabilities is 1.0 - 1.0, they are not printed. Thus an N-category response scale gives rise to N-1.0 HR - FAR pairs. These N-1 pairs may be plotted on linear coordinates to form a bowed Receiver Operating Characteristic Curve (ROC Curve).

7. CUMULATIVE Z-SCORE PROBABILITIES: These are the Z-score transforms of the above cumulative probabilities based on the normal distribution. Note that the sign of these numbers follows standard statistical convention: Negative Z-scores correspond to probabilities less than 0.5. Thus the sign is reversed from the Signal Detection Theory interpretation of the Hit Rate Z-Score (HR_Z) and the False Alarm Rate Z-Score (FAR_Z). These N-1 pairs may be plotted on linear coordinates to form a linear ROC curve.

8. INITIAL VALUES: These estimates of the signal detection parameters are based on the least-squares regression of the equation:

$$HR_z = A + B \cdot FAR_z$$

9. FINAL VALUES: These estimates of the signal detection parameters are based on the maximum likelihood solution to the linear equation:

$$HR_z = A + B \cdot FAR_z$$

SIGNAL DETECTION PARAMETERS

"A" The estimate of the numerical value of "A" in the equation

$$HR_z = A + B \cdot FAR_z$$

$A = B \cdot$ (Delta m). When the numerical value of $B = 1.0$, $A = d'$

"B" The estimate of the numerical value of "B" in the equation

$$HR_z = A + B \cdot FAR_z$$

"B" is the slope of the above function and represents the ratio of the standard deviation of the noise distribution to the standard deviation of the signal plus noise distribution:

$$B = \frac{\sigma_n}{\sigma_{sn}} \quad \text{Since } \sigma_n = 1.0 \text{ (assumed)},\ \sigma_{sn} = 1.0/B$$

"DELTA M" The numerical value of the mean of the signal plus noise distribution expressed in terms of the standard deviation of the noise distribution. It is assumed that $\sigma_n = 1.0$ and $\mu_n = 0.0$.

$$\text{DELTA M} = A / B$$

When $B = 1.0$, DELTA $M = A = d'$. Delta $m = \mu_{sn}$

"D(A)" The calculated value of d_a, the detectability coefficient to be used in place of d', when the variances of the noise and the signal plus noise distributions are not equal. See Simpson and Fitter, 1973, for a discussion of this index. When $B = 1.0$, $d_a = d' =$ delta $m = A$.

$$d_a = \left(\frac{2}{(1+B^2)}\right)^{\frac{1}{2}} \cdot A$$

"Z(K)" These are the numerical values of the various decision criteria used by the subject to divide up the response into the various response categories. The numbers are on a scale of standard deviation units (z-scores) of the noise distribution. A negative z value indicates a criterion to the left of the noise distribution mean, a positive z value indicates a criterion to the right of the noise distribution mean.

"BETA" These are the numerical values of the various decision criteria expressed in terms of the likelihood ratio at each of the above z values. The values of beta are given by:

$$\text{BETA} = \frac{f(x)_{sn}}{f(x)_n} \quad \text{where x is the z(k) value given above.}$$

$$f(x)_n = \left(\frac{1}{\sqrt{2\pi}}\right) \text{EXP-}\left[\frac{x^2}{2}\right] , \quad f(x)_{sn} = \left(\frac{1}{\sigma_{sn}\sqrt{2\pi}}\right) \text{EXP-}\left[\frac{(x-\mu_{sn})^2}{2\cdot\sigma_{sn}^2}\right]$$

"CHI SQUARE" This statistic is used as a "goodness-of-fit" measure. If the final value of chi square is significant for the degree of freedom indicated, it means that the signal detection model does NOT account for all the variance in the data from the experiment. If chi square is not statistically significant, we can conclude that the signal detection model provides a satisfactory description of the behavior in the rating scale signal detection experiment.

"LOG L" The log of the likelihood that is being maximized by the computer program.

"VARIANCE-COVARIANCE MATRIX" The negative diagonal of the matrix contains the variance of the estimation of the parameters A, B, and the Z criterion cut-offs and can be used to calculate confidence intervals.

PUNCHED OUTPUT

If CARD 1 contains a 1 in column 15, the program will write onto TAPE4, three records containing the following information:

```
SUBNO,  KK, A, B, DELTAM, DSUBA    (214,   7X     ,8F10.4)
SUBNO,  KK, Z(K), K=1,KK)          (214,*  Z(K)  *,8F10.4)
SUBNO,  KK, BETA(K), K=1,KK        (214,*  BETA  *,8F10.4)
```

```
Where       SUBNO = Subject number (from card 1)
            KK    = Number of criteria points
            A     = Signal Detection Parameter "A"
            B     = Signal Detection Parameter "B"
            DELTAM= Signal Detection Parameter "DELTA M"
            DSUBA = Signal Detection Parameter "da"
            Z(K)  = Z-score criterion cut-off (KK of them)
            BETA  = Beta criterion values (KK of them)
```

These values could be read from the file by another program using this input read format:

```
FORMAT(2I4,7X,8F10.4)
```

It will be necessary for the user to save or dispose TAPE4 file at the end of an RSCORE run. Otherwise the information on the file will be lost.

```
SAVE(TAPE4=MYDATA)
DISPOSE(TAPE4=PU)
```

PROGRAM CARD

Those of you skilled in file manipulations might make use of the ability of KRONOS 2.1 to change file assignments at run time. The program card looks like this:

```
PROGRAM RSCORE(INPUT,OUTPUT,TAPE4, TAPE5=INPUT,TAPE6=OUTPUT)
```

APPENDIX E

SIGNAL RSCORE OUTPUT

```
ESTIMATES OF SIGNAL DETECTION PARAMETERS FROM CONFIDENCE RATING DATA

CDC 6400 VERSION BY LEWIS O. HARVEY, JR.
26 SEPTEMBER 1973.

SUBJECT NUMBER     1      I(INSTRUCTION TYPE) EXPERIMENT 1

NUMBER OF NOISE TRIALS =    63.      NUMBER OF SIGNAL TRIALS =    57.

RESPONSE FREQUENCIES
            1           2           3           4
  N        18.         31.         12.          2.
 S+N        3.         11.          5.         38.

RESPONSE PROBABILITIES
            1           2           3           4
  N      .2857       .4921       .1905       .0317
 S+N     .0526       .1930       .0877       .6667

CUMULATIVE PROBABILITIES
            1           2           3
  N      .7143       .2222       .0317
 S+N     .9474       .7544       .6667

CUMULATIVE Z-SCORE PROBABILITIES
            1           2           3
  N      .5656      -.7645     -1.8561
 S+N    1.6202       .6831       .4303

INITIAL VALUES, BASED ON LEAST SQUARES SOLUTION, ARE:

               A            B          DELTA M        D(A)
            1.2546        .4939        2.5148        1.5877

 Z(K)=      -.5656        .7645        1.3561
 BETA=       .1797        .4564        2.3165

CHI SQUARE=       4.7104   DF= 1              LOGL=   -128.3912


PROCEDURE CONVERGED IN    4 ITERATIONS.   FINAL VALUES   ARE:

               A            B          DELTA M        D(A)
            1.2187        .4796        2.5408        1.5533

 Z(K)=      -.5932        .8455        1.6500
 BETA=       .1848        .4926        1.9587

CHI SQUARE=       3.1026   DF= 1              LOGL=   -127.3957

VARIANCE-COVARIANCE MATRIX
            A              B              Z1             Z2             Z3
 A     .4525E-01      .1387E-01     -.9845E-02     -.9059E-02     -.6071E-02
 B     .1387E-01      .1599E-01     -.4347E-02      .2269E-02      .1500E-01
 Z1   -.9845E-02     -.4547E-02      .2[illegible]E-01      .1009E-01      .4929E-02
 Z2   -.9059E-02      .2269E-02      .1009E-01      .3024E-01      .2582E-01
 Z3   -.6071E-02      .1500E-01      .4[illegible]E-02      .2582E-01      .6707E-01

THE FOLLOWING VARIABLES HAVE BEEN WRITTEN ON TAPE4:
SUBNO, KK, A, B, DELTAM, DSUBA (2I4,    7X     ,4F10.4)
SUBNO, KK, Z(I),I=1,KK             (2I4,'  Z(K) ',8F10.4)
SUBNO, KK, BETA,I=1,KK             (2I4,'  BETA ',8F10.4)
```

APPENDIX F

SIGNAL DETECTION PARAMETERS FOR EACH SUBJECT
WITH AVERAGED Z(K) AND BETA VALUES

1	1		1.2197	.4796	2.5408	1.5539
1	1	Z(K)	.6444			
1	1	BETA	.5481			
5	1		1.3242	.3912	3.3250	1.7440
5	1	Z(K)	1.2066			
5	1	BETA	.7981			
12	1		1.3464	.1315	10.2402	1.8879
12	1	Z(K)	.8096			
12	1	BETA	.1022			
15	1		1.2012	.4829	2.4873	1.5297
15	1	Z(K)	.6480			
15	1	BETA	.5360			
18	1		.4077	.1433	2.8442	.5707
18	1	Z(K)	1.8011			
18	1	BETA	.8557			
25	1		1.5224	.1916	7.9459	2.1145
25	1	Z(K)	1.5939			
25	1	BETA	.5174			
29	1		.9605	.4779	2.0099	1.2255
29	1	Z(K)	.3529			
29	1	BETA	1.0303			
31	1		1.4913	.4013	3.7169	1.0573
31	1	Z(K)	.7981			
31	1	BETA	.8495			
33	1		.6082	.4370	1.3919	.7882
33	1	Z(K)	.8097			
33	1	BETA	1.3806			
35	1		1.0818	.2104	5.1413	1.4971
35	1	Z(K)	1.2665			
35	1	BETA	.8508			
38	1		.9836	.1370	7.1794	1.378[illegible]
38	1	Z(K)	1.1030			
38	1	BETA	[illegible]			
40	1		2.6517	.2590	10.2393	3.6302
40	1	Z(K)	.9617			
40	1	BETA	.0375			
2	1		.7102	.4337	1.6378	.9215
2	1	Z(K)	1.0606			
2	1	BETA	.9752			
6	1		.2839	.6048	.4695	.3436
6	1	Z(K)	-.0357			
6	1	BETA	1.6105			
8	1		1.1312	.5203	2.2896	1.4944
8	1	Z(K)	.6736			
8	1	BETA	.6238			
11	1		.9102	.1905	4.7792	1.2645
11	1	Z(K)	1.8142			
11	1	BETA	2.8459			
14	1		1.3716	.3917	3.5019	1.8061
14	1	Z(K)	.8372			
14	1	BETA	.6282			
17	1		.9937	.3529	2.8159	1.3252
17	1	Z(K)	.6606			
17	1	BETA	.3898			
22	1		1.6362	.3069	5.3322	2.2121
22	1	Z(K)	.9112			
22	1	BETA	.5426			
27	1		1.2950	.2859	4.5265	1.7482
27	1	Z(K)	[illegible]			
27	1	BETA	[illegible]			
25	1		[illegible]	.0079	-8.8820	-.0984
25	1	Z(K)	[illegible]			

APPENDIX F (CONT)

14	1	Z(K)	.3793			
14	1	BETA	.5714			
17	1		.7031	.5772	1.2180	.8611
17	1	Z(K)	-.2743			
17	1	BETA	.9563			
23	1		1.2215	.1427	8.5627	1.7102
23	1	Z(K)	.3524			
23	1	BETA	.1485			
2	1		1.4428	.2735	5.2764	1.9682
2	1	Z(K)	.3293			
2	1	BETA	.3778			
6	1		.8650	.2629	3.2942	1.1844
6	1	Z(K)	.8538			
6	1	BETA	.4065			
7	1		.5782	.4589	1.2599	.7431
7	1	Z(K)	.5346			
7	1	BETA	.7151			
12	1		.7720	.5415	1.4256	.9600
12	1	Z(K)	.4253			
12	1	BETA	.5924			
15	1		91.7706	38.4877	2.3844	3.3709
15	1	Z(K)	2.3894			
15	1	BETA	644.1697			
18	1		.5369	.5159	1.0408	.6748
18	1	Z(K)	.0217			
18	1	BETA	.8213			
20	1		-.0451	.4522	-.0996	-.0561
20	1	Z(K)	-.7571			
20	1	BETA	1.7804			
22	1		.9165	.0033	278.1123	1.2962
22	1	Z(K)	.9627			
22	1	BETA	.0109			
3	1		5.6750	2.8307	2.0048	2.6733
3	1	Z(K)	1.9884			
3	1	BETA	19.9435			
5	1		1.2569	.7741	1.6236	1.4066
5	1	Z(K)	.7160			
5	1	BETA	1.1420			
10	1		1.0137	.4360	2.3251	1.3142
10	1	Z(K)	.4943			
10	1	BETA	.9979			
11	1		.8595	.4037	2.1290	1.1271
11	1	Z(K)	.1646			
11	1	BETA	1.1707			
16	1		.8683	.7034	1.2345	1.0044
16	1	Z(K)	.3111			
16	1	BETA	1.1853			
19	1		1.3164	.3084	3.5732	1.7469
19	1	Z(K)	1.2166			
19	1	BETA	.6396			
21	1		40.7249	16.7268	2.4347	3.4371
21	1	Z(K)	2.3894			
21	1	BETA	217.2438			
24	1		1.4399	.2634	5.4656	1.9691
24	1	Z(K)	1.5623			
24	1	BETA	.7363			

APPENDIX F (CONT)

28	1	BETA	.0296			
32	1		1.5329	.2768	5.5389	2.0893
32	1	Z(K)	.4334			
32	1	BETA	.3349			
34	1		1.3279	.1528	8.6917	1.8564
34	1	Z(K)	1.1209			
34	1	BETA	.2270			
37	1		.8143	.1231	6.6134	1.1430
37	1	Z(K)	.9973			
37	1	BETA	.2050			
3	1		.2807	.6017	.4665	.3402
3	1	Z(K)	-.0849			
3	1	BETA	1.2721			
4	1		1.9567	1.0000	1.9567	1.9567
4	1	Z(K)	1.5264			
4	1	BETA	2.9224			
7	1		1.6714	.1131	14.7837	2.3498
7	1	Z(K)	1.4801			
7	1	BETA	.1552			
10	1		1.1145	.0893	12.4053	1.5699
10	1	Z(K)	1.2587			
10	1	BETA	.1472			
13	1		1.5716	.1557	10.0917	2.1961
13	1	Z(K)	1.3705			
13	1	BETA	.3103			
19	1		1.2101	.2144	5.6430	1.6733
19	1	Z(K)	.9817			
19	1	BETA	.2807			
20	1		1.3515	.1574	8.5867	1.8881
20	1	Z(K)	1.3735			
20	1	BETA	.3591			
23	1		1.0942	.0419	26.1319	1.5460
23	1	Z(K)	1.1089			
23	1	BETA	.0603			
24	1		1.1934	.0090	131.9989	1.6877
24	1	Z(K)	1.2334			
24	1	BETA	.0294			
26	1		1.4161	.2177	6.5058	1.9568
26	1	Z(K)	.9915			
26	1	BETA	.2845			
42	1		1.7297	.2115	8.1786	2.3932
42	1	Z(K)	1.1570			
42	1	BETA	.2398			
43	1		1.8728	.2612	7.1710	2.5626
43	1	Z(K)	1.2527			
43	1	BETA	.2051			
1	1		1.1218	.2089	5.3703	1.5530
1	1	Z(K)	-.2330			
1	1	BETA	.3701			
4	1		.6844	.3788	1.8069	.9052
4	1	Z(K)	-.1199			
4	1	BETA	.6762			
8	1		.9324	.1120	8.3275	1.3104
8	1	Z(K)	1.3083			
8	1	BETA	.2798			
9	1		.8777	.4148	2.1163	1.1465
9	1	Z(K)	-.1527			
9	1	BETA	.6387			
13	1		.2652	.5385	.6799	.4559
13	1	Z(K)	.2711			
13	1	BETA	1.2975			
14	1		.8048	.3739	2.1523	1.0060

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